ELECTRICITY AND ELECTRICAL APPARATUS

W. B. CLAYTON JAS. W. CRAIG

PUBLISHED BY
Association Technical Institute
Y. M. C. A. Lynn, Mass.

A GENERAL TREATISE

ON

ELECTRICITY

AND

ELECTRICAL APPARATUS

BY

W. B. CLAYTON AND JAS. W. CRAIG

Associate Members American Institute of
Electrical Engineers

BOSTON, MASS.

FIRST EDITION ... SECOND THOUSAND

PUBLISHED BY

ASSOCIATION TECHNICAL INSTITUTE

YOUNG MEN'S CHRISTIAN ASSOCIATION

LYNN, MASS.

E. Newton Smith, Director

In preparing the text, the Authors have had valuable assistance from the following Engineers:

J. P. CATLIN, E.E.

A. DEFOREST DAVIS

J. M. BRODIE, B. S.

H. P. HASTINGS, E. E.

PRESS OF THOS. P. NICHOLS & SONS
LYNN, MASS.

PREFACE

The Authors wish to avail themselves of this opportunity to give a few words in explanation of the ground covered in the following pages and the way in which the subject has been presented. The ordinary explanations and discussions of static electricity and other matters of theoretical interest only, such as are found in any high school physics, have been avoided. The aim has been to make the book practical and utilitarian throughout, with the sole object and endeavor to make the subject matter such as will be of immediate use to the reader.

In many parts of the book some particular piece of apparatus or very important division of the subject, such as Wiring, has been allowed only a few pages. The Authors anticipate possible criticism for the superficial manner in which some of the important points have been taken up, but it is admittedly impossible to cover thoroughly in detail, in one volume, all of the broad field touched upon. The idea has been to give the reader the most comprehensive, and at the same time the greatest, amount of useful knowledge in a given space. Care has been exercised to make the explanations clear and the text interesting.

Friends and Associates are to be thanked for valuable and timely suggestions. The Authors feel deeply indebted to Mr. E. E. Boyer, Electrical Superintendent of the General Electric Company, Lynn, Mass., for his kind advice and thorough reading of the proofs and revision of many particulars of the subject matter. Thanks are also due the Inspection Department of the Associated Factory Mutual Fire Insurance Companies, for the use of several illustrations for the chapters on interior and exterior wiring, taken from the book of rules published by that department.

THE AUTHORS.

CONTENTS

A GENERAL TREATISE ON

ELECTRICITY

AND ELECTRICAL APPARATUS

CHAPTER I

ELECTRICITY

The Many Ways in Which the Flow of an Electric Current is Similar to the Circulation of Water in Pipes — A Simple Circuit — The Meaning of the Terms: Volt and Ampere.

PIECES of sealing wax or amber briskly rubbed on flannel or woolen cloth acquire a peculiar property, and bits of wood fibre or paper will be attracted and stick to the amber or wax if it is held near them.

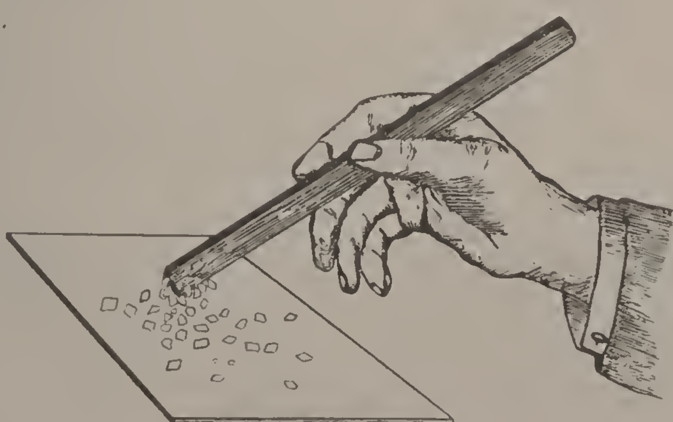


FIG. 1.—ELECTRIFIED SEALING WAX.

This peculiar physical property of amber was first noticed by a Grecian philosopher in ancient times. Later on, in about the year 1600, Dr.

Gilbert, an English Scientist, discovered that other substances besides amber — such as glass, resin, and sulphur — also possessed a similar quality. He called these substances "electrics," and since that time, the name electricity has been used to denote the invisible agent or power, which causes this mysterious manifestation or action of the amber or sealing wax.

It has often been said that we do not know exactly what electricity is. While to a certain extent this may be true, we are so well acquainted with its actions under almost every condition that we lose sight of the fact that its exact nature still remains unknown.

Rubbing the amber or sealing wax causes the change noted, and when produced in this way, the electricity is present in static* charges only, and does not flow in a continual current. For these reasons, when so produced, it is called **static** or frictional **electricity.**

Sometimes the leather belts used to drive machinery may be a little loose and slip on the pulleys. The friction due to the slipping of such belts produces static electricity which manifests itself or discharges in the form of sparks if the hand or fingers are held near them. This discharge consists of a single spark, or series of sparks, and not of a continual stream.

For this reason, static electricity is unsuitable for many commercial applications, also the amount obtainable by rubbing sealing wax is too small to be of practical value for such purposes as furnishing light, and operating electric motors similar to those used on electric cars or on machine tools.

Friction and influence-machines are manufactured which can produce greater quantities of static electricity than it is possible to obtain from the sealing wax or glass rod. Figure 2 illustrates

* Static,— stationary; not in motion.

a Toepler-Holtz influence-machine from which heavy charges of static may be obtained. Large machines, similar to this, are often used by physicians for medical purposes.

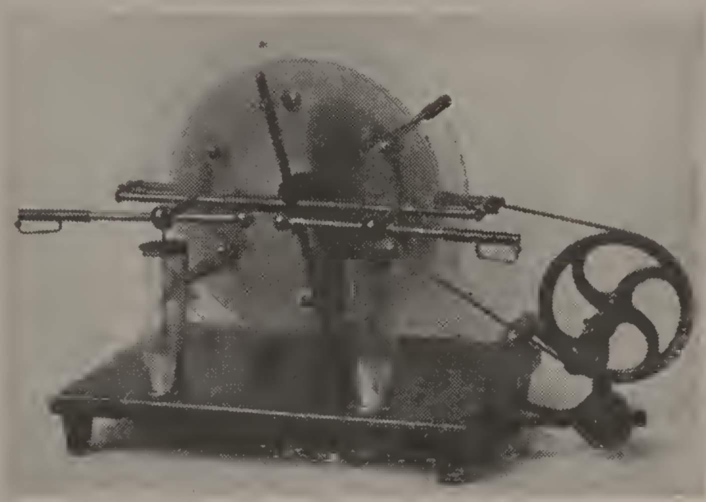


FIG. 2.—TOEPLER-HOLTZ INFLUENCE MACHINE.

Electricity may also be produced by batteries. When obtained in this way, it flows in a continual stream, and is called **"current electricity."** A simple cell may be made by partially filling an ordinary glass jar with a solution of sulphuric acid and water, in which must be suspended a piece of zinc and a piece of copper. If a wire is attached to each of these metals, and the ends connected together, a current of electricity will flow. If allowed to continue flowing for some little time, a noticeable eating away of the zinc plate will result. In other words, the zinc is being burned chemically, and it is this chemical action which gives the energy necessary to the production of the electrical current. A current so produced is said to be **"chemically generated."** It should always be remembered that electricity is a form of energy, and for its production or generation an expenditure of energy is necessary. Thus, the length of time a cell like this could supply

current would be limited by the size of the zinc plate and the amount of acid solution available.

Another factor affecting the output of the cell is known as polarization, which consists of the formation of small bubbles of hydrogen gas on the copper plate, caused by the chemical action decomposing the water into its constituents, hydrogen and oxygen. These bubbles decrease the power of the cell. However, this action takes place only while the cell is active, and when it is not in use, part of these bubbles disappear and the cell regains some of its lost strength.

Polarization causes many cells or batteries—such as the common dry battery—to "run down" if left connected to a circuit and used for long periods. Thus, "open circuit" batteries, when not in use, should be disconnected in such a way as to prevent the flow of current.

There are several different types of open circuit batteries on the market, working on the same principle as the above described simple cell, but using various metals for the plates and different solutions; in some cases a special chemical is added to the solution to reduce the polarizing action to a minimum.

The ordinary **dry cell** or **battery,** as indicated by the name, is apparently without any acid solution; one plate is a carbon stick in the center, and the other is a sheet of zinc made in a hollow cylindrical shape, forming the vessel in which the other parts of the cell are placed. Care must be taken to keep the carbon and zinc from coming in contact with each other. The space between the plates is packed with a mixture of powdered carbon, manganese dioxide, and some absorbent material, like sawdust. This combined mixture is saturated with a solution of sal-ammoniac (ammonium chloride).

Another class of batteries is known as "Closed Circuit," and these are often used where current is required for long periods of time. They differ

from the open circuit batteries in respect to the duration of their current-furnishing power.

The **Gravity Battery** is the foremost of this class and the only one worthy of mention. It consists of a "crowfoot" of zinc placed in the top of a jar containing a solution of copper sulphate or bluestone. In the bottom of the jar is the copper plate.

Open circuit batteries are used for door-bells, and places where current is necessary only for short intervals. Dry batteries are a special form of open circuit batteries, being utilized where convenience is desired. Closed circuit cells are suitable where currents are required over long periods of time. The gravity cell has been widely utilized in telegraph work, but are now being superseded by motor-generator sets.

Both open and closed circuit types are called primary batteries, as they are the primary or original source of the current. Storage batteries, sometimes known as accumulators or secondary batteries, are taken up later.

Currents from primary batteries are suitable for purposes where only small amounts of electricity are required. If, however, several ordinary incandescent lamps are to be lighted, or a large electric motor operated, it would require very many of these cells or batteries to furnish a sufficient amount of electricity. As this would make an extremely unhandy and expensive arrangement, batteries are seldom used for this purpose. Instead, special machinery is installed in electric lighting plants or central stations, which generate an electric current large enough to light several thousand lamps or operate large motors. These machines, called dynamos or generators, are driven by steam or gas engines, turbines or water wheels. Current thus produced is said to be **mechanically generated.**

In the study of electricity it is well first to become familiar with electric currents themselves and

their action under various circumstances, before we proceed to the study of the machines and principles by which electricity is produced or generated.

In many ways the **flow of electricity** can be likened to the **circulation of water** in pipes. The transmitting or passing of an electric current through wires— such as are stretched along the street, suspended from poles — is very similar to a stream of water flowing through a level pipe. To make the water flow through the pipe it is necessary to have a pump or some means whereby we can get a pressure to force the water along. This pressure is necessary to overcome the friction which the water meets in flowing through the pipe.

In Fig. 3, if the faucet is closed and water is poured into the left-hand reservoir, it will flow to

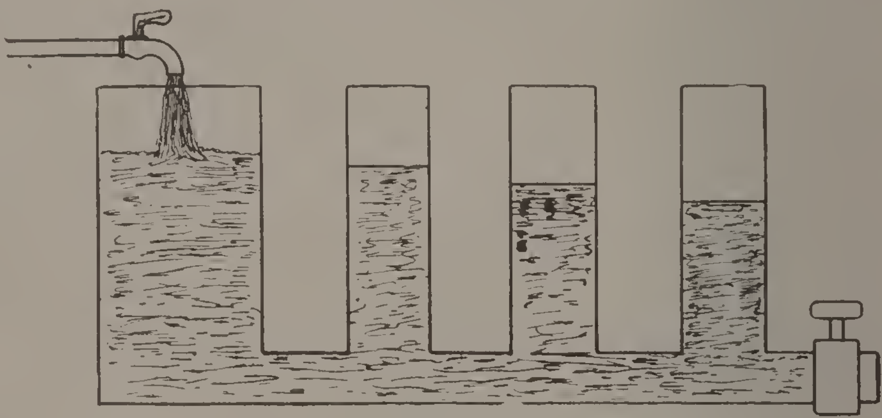


Fig. 3.

the right until the level in the different vertical tubes is the same. As long as there is a difference in level, or in other words, a difference of pressure, the water will flow.

Fig. 4 represents a stream of water passing or circulating around through a system of pipes. The water leaves the pump at a certain pressure, which causes it to flow through the pipes, whence it emerges, coming into contact with the water-wheel and losing the larger part of its pressure in turning the wheel. It then falls into the tank and returning to the pump by suction through the

bottom pipe, is again given a fresh impulse, and passes out from the pump along the same course.

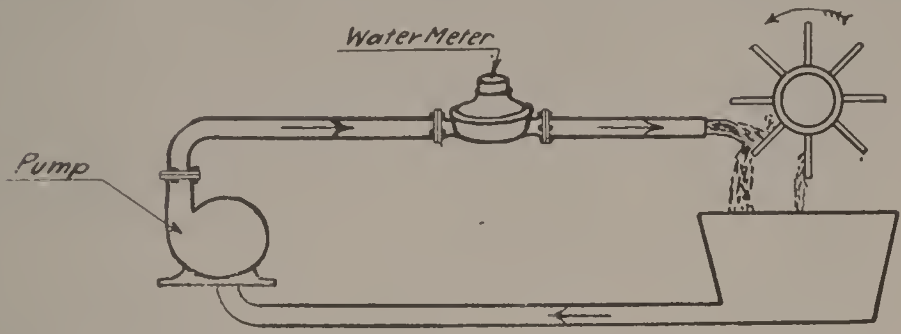


FIG. 4.—HYDRAULIC ANALOGY OF ELECTRIC CIRCUIT.

The quantity of water flowing in the pipe, may be determined by ascertaining the number of gallons that pass a given point in the pipe during a certain period of time. This can be done by placing a water meter in the pipe line as shown, or if the pressure is known, by measuring the cross section of the stream.

The water is being delivered from the pump at a certain pressure, measured and expressed as so many pounds per square inch; while the water in the bottom pipe is under only a small pressure due to suction. In other words, there is a difference in pressure between the outlet and inlet of the pump, and the water will continue to flow only so long as this difference in pressure exists. In like manner an electric current will not flow of its own accord. It requires a force or pressure to overcome the resistance offered to its passage as it flows through the wire. **Electricity** is much like a **weightless fluid**—flowing or being conducted along or through the solid wire from particle to particle.

There are many striking similarities in Fig. 5, which represents the production and utilization of electricity. The dynamo from which the electric potential is generated is shown on the left by a circle. A battery would also serve the purpose. In the ordinary case, the dynamo is, of course, located in the central station or power house and the current

is generated at a certain voltage or pressure, passed out along the wires in the streets to the customer's

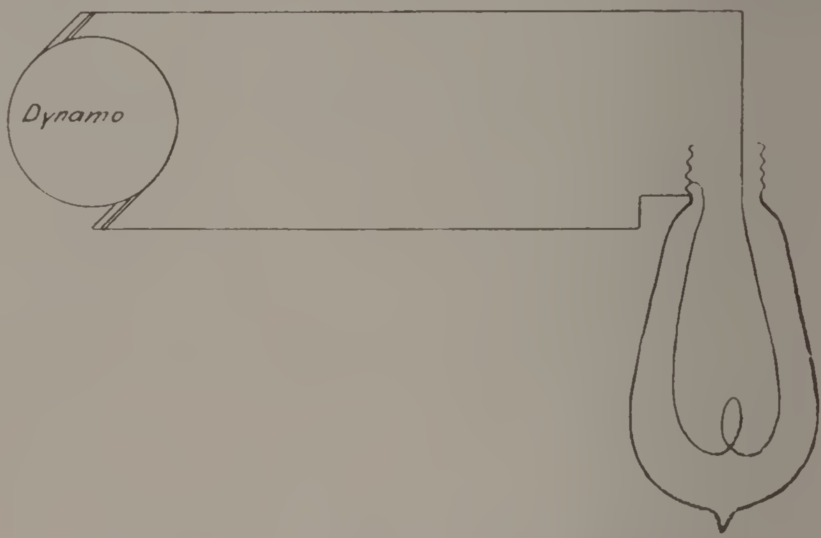


FIG. 5.—A SIMPLE ELECTRIC CIRCUIT.

premises and thence into the house where the electric current is to be used. The pressure causes it to flow through the lamps or motors and to do its work, after which it returns by means of the second or bottom wire to the dynamo, where the pressure is again supplied and the current flows out over the same path.

As in the pump and pipes, there is a difference in pressure between the two wires. This pressure is not measured in pounds per square inch as in the case of the water, but in another unit called the **volt,*** and on an ordinary circuit, where there are incandescent lamps inserted, the pressure required to force the proper amount of electricity through a lamp filament is 110 volts. As the current flows the filament is heated, becomes incandescent and gives out light.

Ampere* is the unit of current. If we know the number of amperes, it at once gives us an idea of the volume of the current, just as a clear idea of the size of a stream of water is gained when the cross section of the pipe is ascertained.

* Definitions and values of the electrical units, Volt, Ampere, and Ohm, will be found in Appendix I.

CHAPTER II

MAGNETISM

Permanent Magnets —Magnetism and Magnetic Laws — Earth's Magnetism — Compass Needle.

If a horseshoe magnet is brought near a small piece of iron, it will attract and hold the iron as shown in Fig. 6. Also, steel pens, iron nails, and many other articles can be easily picked up, and, if the magnet is powerful, such substances as nickel and cobalt are noticeably attracted. We say this power is magnetism and the substances so affected are "magnetic." On the other hand a copper cent, a silver dime, or a small piece of brass are unaffected — hence such substances are "non-magnetic."

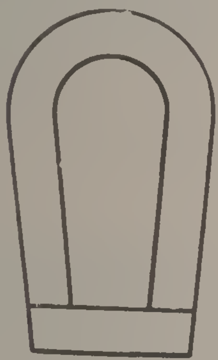


Fig. 6.—Horseshoe Magnet and "Keeper."

Magnetism and magnets play a very important part in the commercial generation and utilization of electricity, being widely used in the various kinds of electrical machinery. In order to understand more clearly their action, let us perform the following experiment: — Lay a horseshoe magnet on a table. On top of the magnet place a piece of glass (heavy stiff paper will serve the purpose, if glass is not available). If fine iron filings are sprinkled over the glass and at the same time it is tapped lightly with a pencil, it will be seen that the filings do not fall haphazard but form along certain definite, curving lines, such as can be seen in Fig. 7.

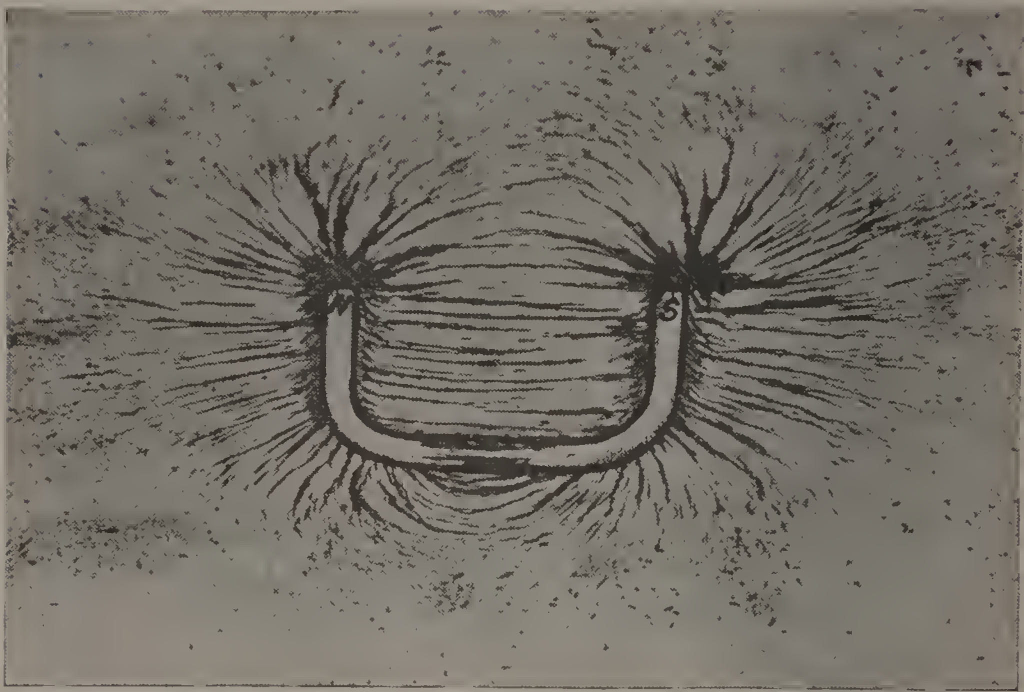


Fig. 7.—Distribution of Iron Filings showing Magnetic Field of a Horseshoe Magnet.

Again, if a small bar magnet is substituted for the horseshoe magnet, we find the iron filings will distribute themselves as illustrated in Fig. 8.

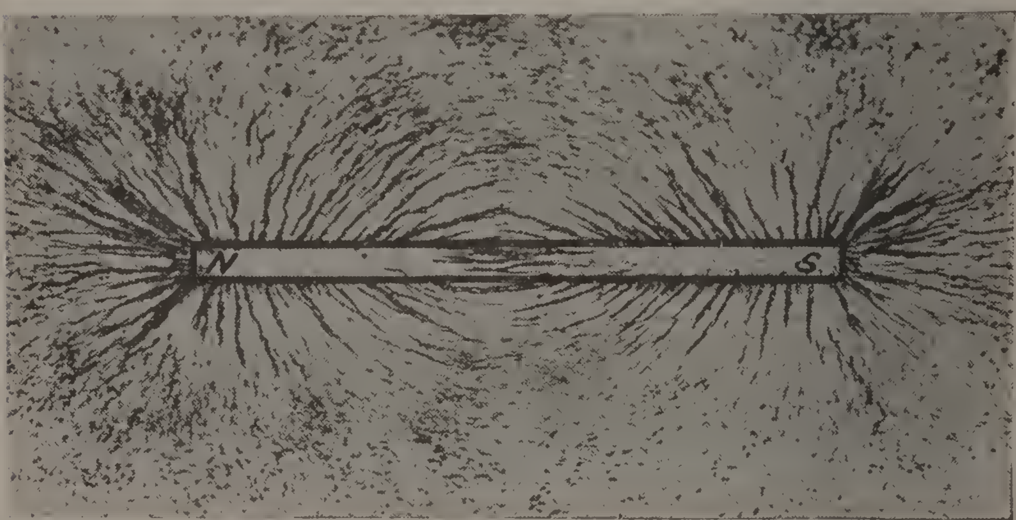


Fig. 8.—Magnetic Field of a Bar Magnet.

If both the horseshoe and bar magnets are held in an upright position beneath the glass, with only the poles or pole coming in contact with the glass, the resulting figures given by the filings will be as illustrated in Figures 9 and 10.

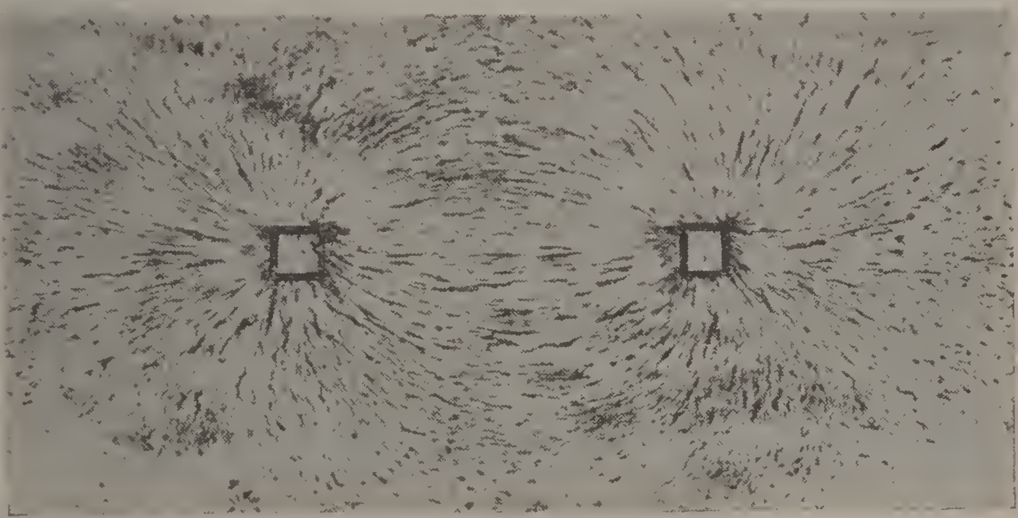


Fig. 9.—Magnetic Field around the Poles of a Horseshoe Magnet.

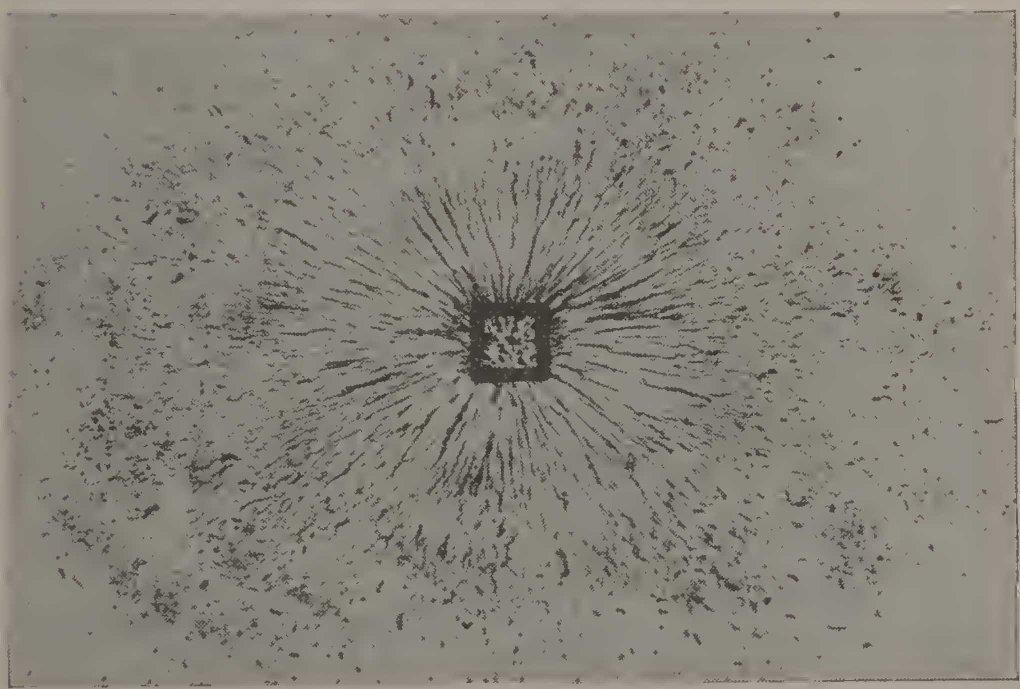


Fig. 10.—Magnetic Field around One Pole of a Bar Magnet.

Naturally the question arises: What makes the filings distribute themselves in such a manner? The space near any magnet is pervaded with magnetic **lines of force** that are invisible, and in the direction or along the lines mapped out by the arrangement of the iron filings. This is called the **magnetic field.** While it is true that these lines of force are invisible, so much has been learned of them and their action under different circumstances, that we even go so far as to count them and determine the number proceeding from a magnet. The strength of a magnetic pole is based on and depends upon the number of these lines. The more of these lines there are, the stronger the magnet, or in other words, the more powerful it will be. These lines of force emerge from one side of the magnet and enter the opposite side. The place where they emerge from the magnet is called the north pole, and where they enter or go into the magnet is called the south pole. Each line of force is a complete ring or link, and the curving path followed in going through the air from the north to the south pole can be explained as follows: The natural tendency of the lines of force is to travel by the path of least resistance, and through the air a straight line would represent the shortest, and consequently the path allowing the easiest, flow. But there is a repulsion between the individual lines of force flowing in the same general direction nearly parallel. This repulsion forces the lines outwards, giving them the curved shapes as illustrated.

If two north poles of two bar magnets are brought near together — each magnet being freely suspended by a string — they will repel each other; and if two south poles are brought near together, they will likewise repel each other. On the other hand, if a north pole of one magnet is brought near the south pole of another magnet, they will attract each other.

The cause for this repulsion and attraction of like and unlike poles will be more easily understood by the following:

Place two bar magnets on the table with their north poles pointing towards each other and on them lay a piece of glass. Iron filings, sprinkled on the glass, will distribute themselves as in Fig. 11.

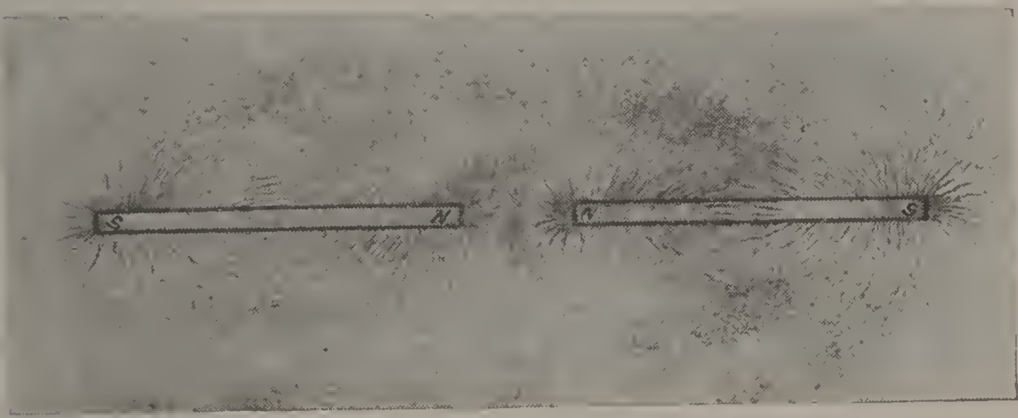


FIG. 11.—MAGNETIC FIELD BETWEEN NORTH POLES OF TWO BAR MAGNETS.

If the magnets are reversed, so that the two south poles point towards each other and the experiment is repeated, the filings assume similar shape, as will be seen in Fig. 12. After emerging from the north

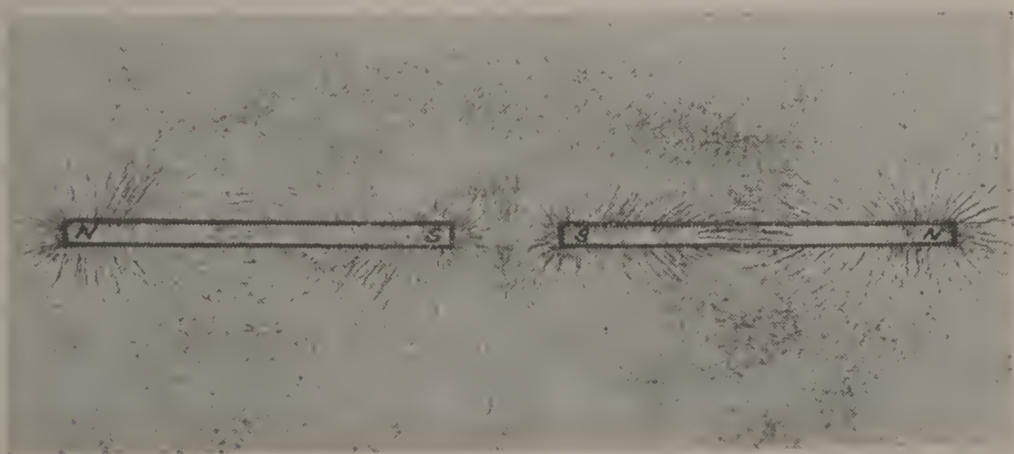


FIG. 12.—MAGNETIC FIELD BETWEEN SOUTH POLES OF TWO BAR MAGNETS.

poles of the magnets in Fig. 11, the lines of force are practically parallel for some distance, and there is a resulting repulsion.

On the other hand, if we place the two magnets with a north pole and a south pole towards each other, the lines of force, shown by the arrangement of the iron filings, will be quite different, as illustrated by Fig. 13. These lines of force emerge

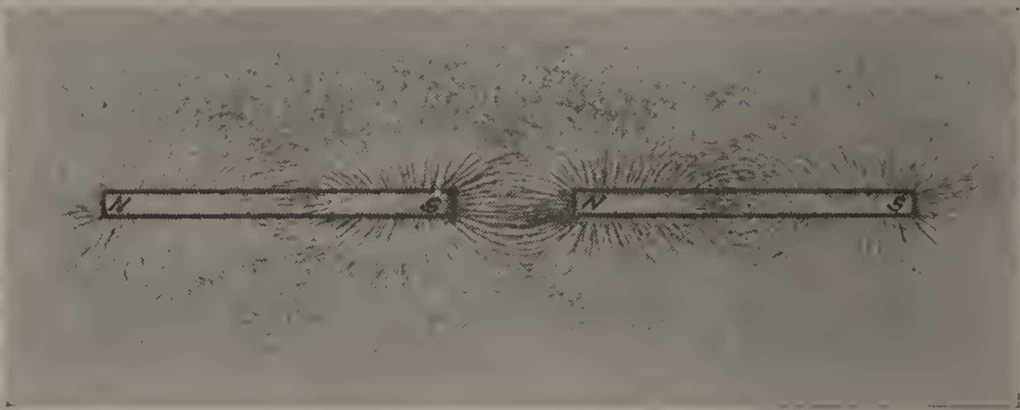


FIG. 13.—MAGNETIC FIELD BETWEEN A NORTH AND A SOUTH POLE.

from the north pole of one magnet and enter the south pole of the other. Since the lines tend to flow along the shortest path, they try to shorten themselves, just as rubber bands will do when stretched, and thus the poles are attracted toward each other. At the same time the lines repel each other, and are forced apart until the pull on each individual line balances the repulsion. This repulsion and contracting action can be plainly seen in Fig. 13.

If a bar magnet, Fig. 14, is cut in halves, we have not obtained two magnets with one pole each, but both magnets have two poles. How does this happen? Because the lines of force which entered the south pole of the original magnet must flow through it, and as they emerge where the bar was cut in two, they form a north pole at that point.

Iron is a magnetic material and allows the lines of force to pass with much less resistance than air. Thus, if a piece of iron is brought near a magnet the

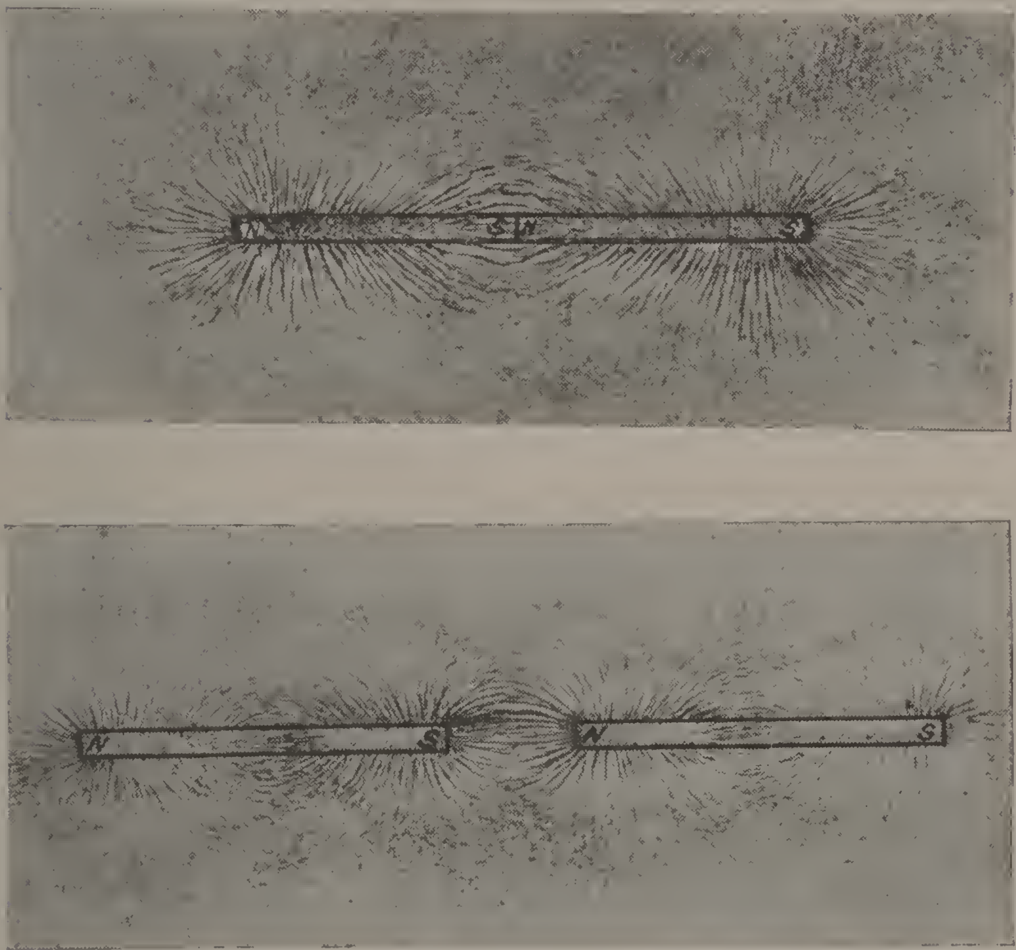


FIG. 14.—EFFECT OF CUTTING A BAR MAGNET IN HALVES.

lines of force will be distorted, as shown in Fig. 15, and on account of the tendency of lines of force to shorten themselves, the piece of iron will be attracted to the magnet.

This could be explained in a different way as follows: Referring to Fig. 15; as the bar magnet is brought near to the piece of iron, some of the lines of force from the north pole of the magnet will enter the piece of iron, pass partly through it, and emerge from the opposite side. The passing of these lines of force through the piece of iron causes it to act as

a magnet. The side nearest the north pole of the magnet becomes a south pole as lines of force are entering at this point. The magnetism in the piece of iron is said to be induced. Now by the law of magnetism, where unlike poles attract each other, the north pole of a bar magnet will attract the south pole of the iron or induced magnet, and in this way the magnet is enabled to pick up the piece of iron which has become a magnet.

Many years ago it was discovered that the earth itself is a great magnet, and that the north and south magnetic poles are not very far from the north and south geographical poles.

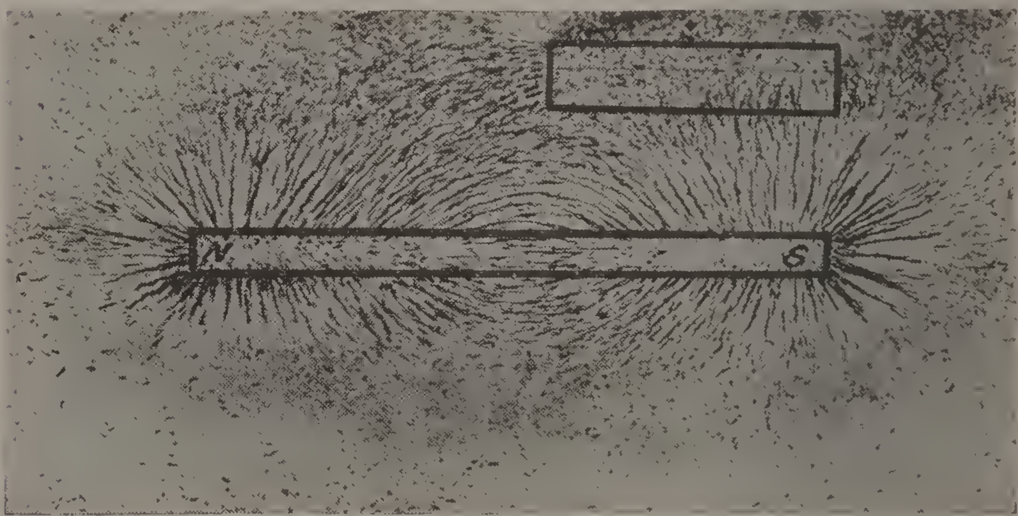


Fig. 15.—Effect of Iron in Distorting the Field of a Bar Magnet.

On this account, if a bar magnet is freely suspended by a string it will set itself in a certain direction, one pole being attracted towards the north pole of the earth and the other toward the south magnetic pole of the earth.

There is a peculiar distinction concerning these so-called north or south poles of magnets that should be thoroughly understood. If a bar magnet is suspended, the end pointing northwards is in reality

a north-seeking pole and as it is attracted by the north pole of the earth it must necessarily be of opposite polarity, but ordinarily when a north pole is spoken of we refer to the north-seeking pole or the one from which the lines of force emerge from the magnet.

A compass needle is merely a light bar magnet that will turn easily on a pivot and therefore always points in a north and south direction, if not disturbed by local influences.

CHAPTER III

ELECTROMAGNETS

Magnetic Field Around a Conductor Carrying Current — Production of North and South Poles by a Solenoid.

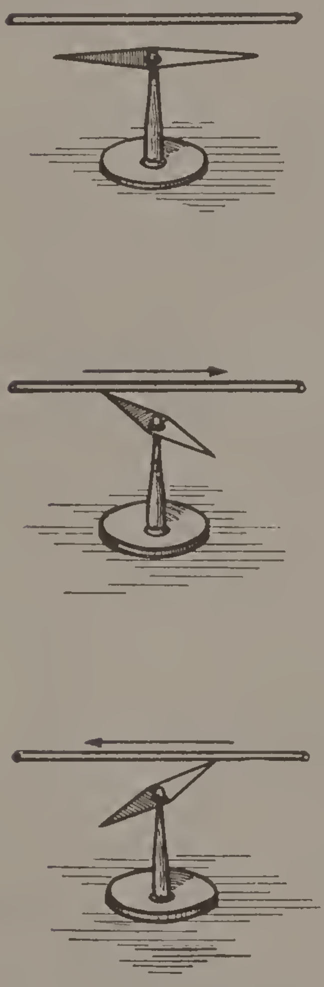


FIGURE 16.— COMPASS NEEDLE, SHOWING EFFECT OF THE ELECTRIC CURRENT.

Under ordinary conditions, the flow of current through or along a wire will not change its external appearance. Yet when current flows, there are many ways in which it can be ascertained that several changes take place, both in the wire and in the space surrounding it.

Over a small compass needle, pointing north and south, hold a wire parallel to it. Then, if the ends of the wire are connected to a battery or source of continuously-flowing current, the needle will suddenly be deflected, or turned out of its north and south direction.

If the ends of the wire which go to the terminals of the battery are changed, so as to reverse the direction of the current through the wire, the deflection of the needle will be in the opposite direction.

A small current will cause a needle to be deflected through a small angle. However, if more batteries are used and a stronger cur-

rent obtained, the deflection of the needle will be increased. The stronger the current—that is, the more amperes that are flowing — the greater will be the deflection of the needle. A large current of a great many amperes will cause the needle to stand at nearly right angles to the wire, or in other words, point very nearly east and west.

Suppose we take a second compass needle and place it directly above the wire: While the current flows it will be found that this second needle will be deflected in the opposite direction to one below the wire. Of course, it is the action or effect from the current in the wire which causes the needle to be deflected. This can be made clearer by the following experiment:

Take a piece of heavy paper or glass, through the center of which a hole has been bored, and through

A ***No Current Flowing***
B ***Current Flowing away from Observer***
C ***Current Flowing up to Observer***

FIG. 17.—COMPASS NEEDLES DEFLECTED BY THE CURRENT IN THE CONDUCTOR.

Note that a circle with a dot in the center represents a conductor with current flowing toward the observer, as though the dot were the point of an arrow. A circle with a cross represents a conductor with current flowing downward away from the observer, the cross indicating the feathered shaft of an arrow as seen from behind.

this pass a vertical wire. If the ends of wire are connected as before to several dry cells of sufficient strength to give a current of 20 amperes, and four small compass needles are placed around the wire at equal intervals from each other — as shown in Fig. 17 — it will be found that all four needles are deflected differently. All four needles point in different directions — approximately 90° apart.

If the ends of the wire going to the battery are exchanged, so as to reverse the direction of the flow of current through the wire, it will be noted that each of the four needles changes its position, or in other words, the direction in which the needles are deflected will be reversed.

Now if the four compass needles are removed and iron filings are sprinkled about the wire, it will be noticed that they distribute themselves in a series of concentric circles around the wire. A still better demonstration of the experiment may be had by slightly tapping or jarring the glass, as this, of course, enables the filings to arrange themselves more easily.

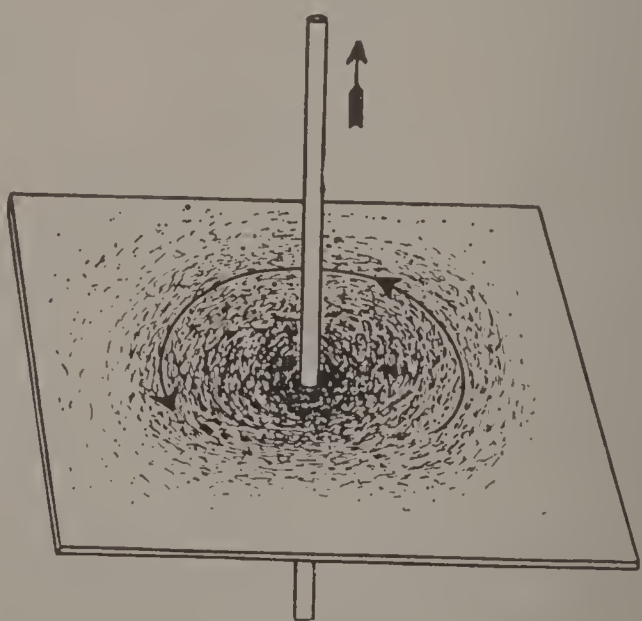


Fig. 18.—Magnetic Field around a Conductor Carrying Current.

These whirls, or circular lines of force, always proceed or rotate in a certain direction with relation to the flow of current in the wire. An easily remembered **rule** to determine the direction of these whirls is: "Take the right hand and lay the thumb along the wire pointing in the direction the current is flowing, then, if the fingers are partly closed, the fingertips will point out the direction of whirls produced."

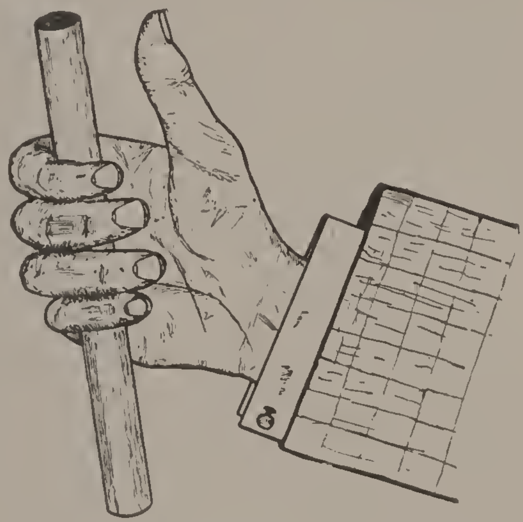


Fig. 19.—Rule to Determine Direction of Magnetic Field around a Conductor Carrying Current. (Right Hand.)

It will be seen that the whirls and flow of current bear the same relation to each other as do the threads and forward travel of an ordinary right-hand screw. These whirls, or circular lines of force, around a conductor carrying current are the same as the magnetic lines of force described in Chapter II. These whirls constitute a magnetic field around the conductor. The more amperes that flow in the wire, the greater the number of whirls produced — that is, the stronger the current, the stronger the magnetic field.

If a piece of wire is wound in several complete turns or convolutions, as shown in Fig. 20, it is

sometimes called a **"solenoid,"** and as a current is passed through the wire, around the turns of the solenoid, there will be a number of magnetic lines

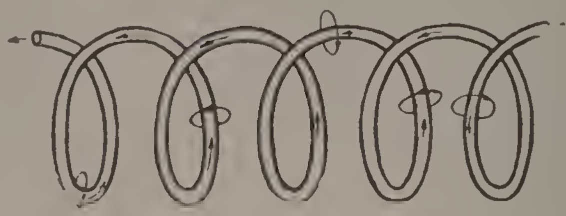


Fig. 20.—Solenoid.

or whirls produced. At first it would seem that these whirls would be as illustrated, but instead of merely flowing around each individual turn of the conductor, all of the lines of force combine with the result as shown in Fig. 21.

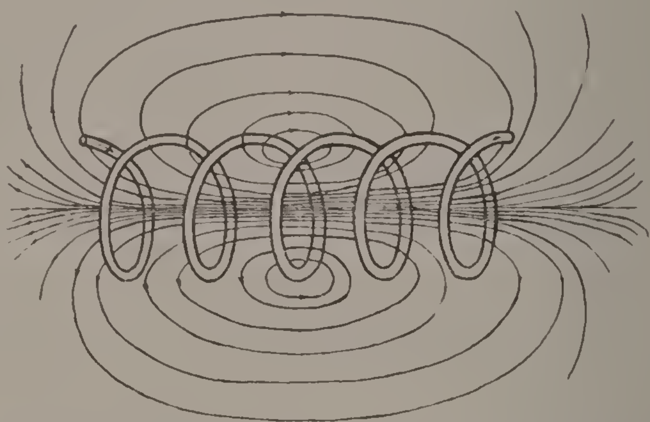


Fig. 21.—Magnetic Flux in a Solenoid.

In this way we can **produce a magnet electrically.** For instance: Suppose a round bar of iron is placed in the middle of a coil of wire through which a current is flowing, the iron will become a magnet (Fig. 22). If the end of the bar which projects from the coil is bent over, we have a horseshoe magnet. To proceed a little further; suppose a second piece of U-shaped iron is inserted in the coil and allowed to come in contact with the first piece, a complete ring or circuit of iron will be produced. As the lines of force leave one piece of iron and enter

the other they have the effect of making a north and south pole, respectively. These attract each other very strongly, as will be found on trying this experiment with apparatus as shown.

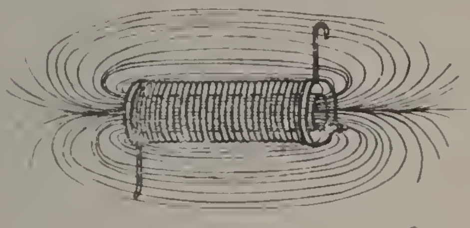


FIG. 22A.—SOLENOID.

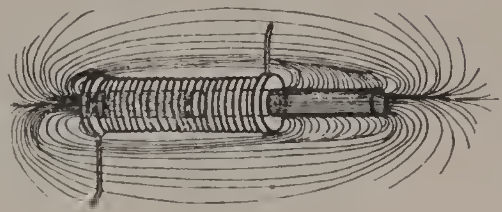


FIG. 22B.—SOLENOID SHOWING DISTORTION OF FIELD DUE TO IRON CORE.

An instructive and interesting experiment can be performed with the apparatus shown in Fig. 24.

Solenoid shown is free to rotate and as ends are dipping in the two parallel grooves of mercury, current flows irrespective of position assumed by coil in its rotation. One end will be a north pole, the opposite, a south. This can be traced out by the rules given.

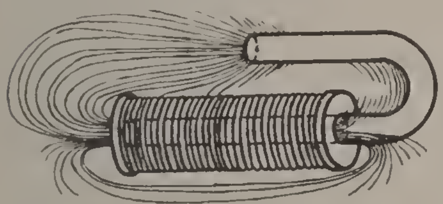


FIG. 23A.—DISTRIBUTION OF LINES OF FORCE WITH U-SHAPED IRON.

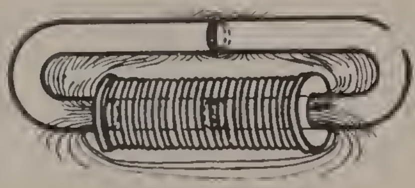


FIG. 23B.—USE OF TWO U-SHAPED CORES, DEMONSTRATING MAGNETIC ATTRACTION.

However, if current is passed through the solenoid, and the north pole of a permanent bar magnet held near, as shown, it will attract the end of the solenoid in which the south pole is formed. The solenoid can be rotated in this way.

It is much easier to magnetize wrought iron than hardened steel. However, steel after being magnetized will retain a large part of the magnetism

even after the magnetizing force is removed. Permanent magnets, such as the small bar and horseshoe magnets, are, for this reason, made of steel and hardened. This may be explained somewhat by the following theory of magnetism:

Fig. 24.—Attraction between a Solenoid or Electromagnet and a Permanent Magnet.

Suppose we place a glass tube, full of pieces or chips of iron or steel, in the center of the solenoid shown in Fig. 20. As a small current is allowed to flow it will be noted that some of the pieces of metal that are comparatively free to move adjust themselves along certain lines. As the current is increased and the magnetizing force becomes stronger, additional pieces of metal move into these lines. On inspection, it will be noted that these lines along which the pieces of metal arrange themselves are identical with those mapped out by the lines in Fig. 21, where the field from a solenoid is represented. If the current is increased still further, more of the remaining metallic pieces are brought into the lines. If the tube is carefully removed from the solenoid, so as not to disturb the arrangement

of the metallic particles, it will be found to act as a magnet. If it is shaken, however, and the arrangement of the particles disturbed — causing them to fall in odd positions, in a confused mass — it will be found that the tube will no longer act as a magnet.

Any body or piece of metal, such as iron or steel, is composed of a number of very small particles which are known as molecules. It has been demonstrated that these little particles or molecules can move to a certain extent with respect to each other and without affecting perceptibly the rigidity of the metal. In any piece of iron each of these molecules is a small magnet, but under ordinary conditions these molecules neutralize each other. A magnetizing force, when applied, causes these small particles to turn and point in the same direction. If the force is sufficiently strong it will cause them all to turn and set themselves along the lines of force. As this is done, the molecules or small magnets no longer neutralize but act together as one big magnet.

These molecules are more difficult to turn in hard steel than in soft iron. Thus, while the iron is easier to magnetize, the hardened steel retains its magnetic powers longer, as the position of the molecules cannot be disturbed as easily.

CHAPTER IV

INSTRUMENTS

Galvanometer—Dynamometer—Ammeter: Hot Wire; Electro-Magnetic; Moving Coil—Voltmeters.

We measure time by means of watches. When coal is bought, for instance, by the ton, it is weighed or measured on scales. When we speak of a large electric current or a small electric current, we refer to the number of amperes flowing.

If merely an indication of the strength of current is desired, and not an exact measurement, an instrument shown in Figure 25 may be used.

FIG. 25.—TANGENT GALVANOMETER.

This is called a **"tangent galvanometer,"** and works on the principle that a compass needle is deflected from a north and south direction by the magnetic lines or whirls produced by the current. It consists of a compass needle situated in the center of a

circular coil composed of several turns, the ends of which are connected to the binding posts on the right.

The deflection of the needle is proportional to the strength of the current in the coil, and the number of turns. Also if the diameter of the coil is changed, the deflection of the needle will be affected correspondingly. As the diameter is increased and the distance between the wires and the needle made greater, the deflection will be smaller for a given current, or, on the other hand, if the diameter of the coil is decreased, bringing the wires closer to the needle, the current will affect the needle more strongly and cause a greater deflection.

In any one galvanometer, where the diameter of the coil and the number of turns are constant, the current regulates the deflections of the needle, and as the strength of the current changes the needle varies in certain fixed proportions.

We have seen, from Chapter II, how magnets will attract or repel each other. Now, likewise, there is an attraction and repulsion between two currents flowing in parallel wires exerted through the magnetic fields surrounding each wire.

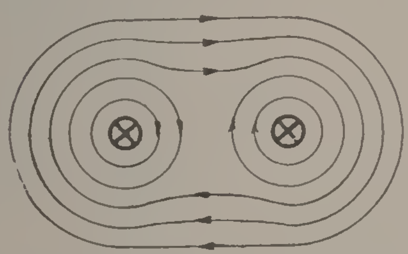


FIG. 26.—MAGNETIC FIELD, TWO WIRES CARRYING CURRENT IN THE SAME DIRECTION.

If two parallel wires are carrying currents in the same direction, the lines of force combine, as illustrated in Fig. 26, and due to the tendency of the lines to contract, there will be a force exerted tending to pull the wires together.

The resultant magnetic field when the two currents are flowing in opposite directions is indicated in Fig. 27. As the lines flow along, side by side in the space between the two wires, there is a repulsion which will tend to force the wires apart.

The number of lines of force is proportional to the current in the two wires; consequently, the strength of this attraction or repulsion depends upon and varies with the currents.

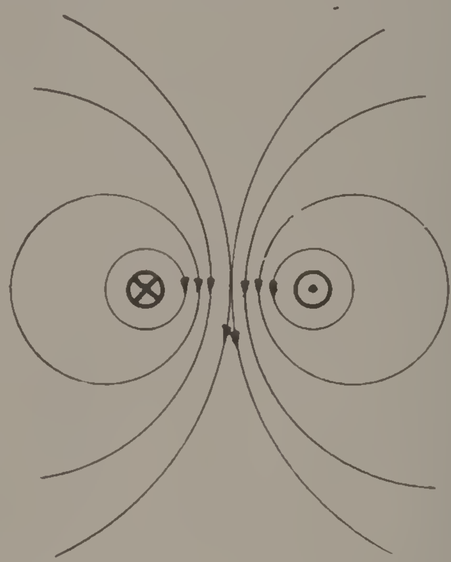


Fig. 27.—Magnetic Field between Two Wires Carrying Current in Opposite Directions.

Fig. 28 represents a device for demonstrating the repulsion or attraction between currents flowing in parallel wires. The square or rectangular coil, as shown, is suspended on a pivot at the top and is free to rotate. The ends of the coil dip into two parallel circular grooves in the base, which are filled with mercury. In this way, connection can be made and is not broken as the coil rotates. The half circular coil and the rectangular coil are connected in series. The current will flow up one side of the rectangular coil and down the other side. Hence, one side of the rectangular coil will be repelled and the other attracted by the current in the straight side of the semi-circular coil.

Dynamometers are constructed on this principle and are used to indicate current strength. One common type consists of two coils, the inner, stationary, and the outer, suspended at right angles to the first. As current passes through both coils, the

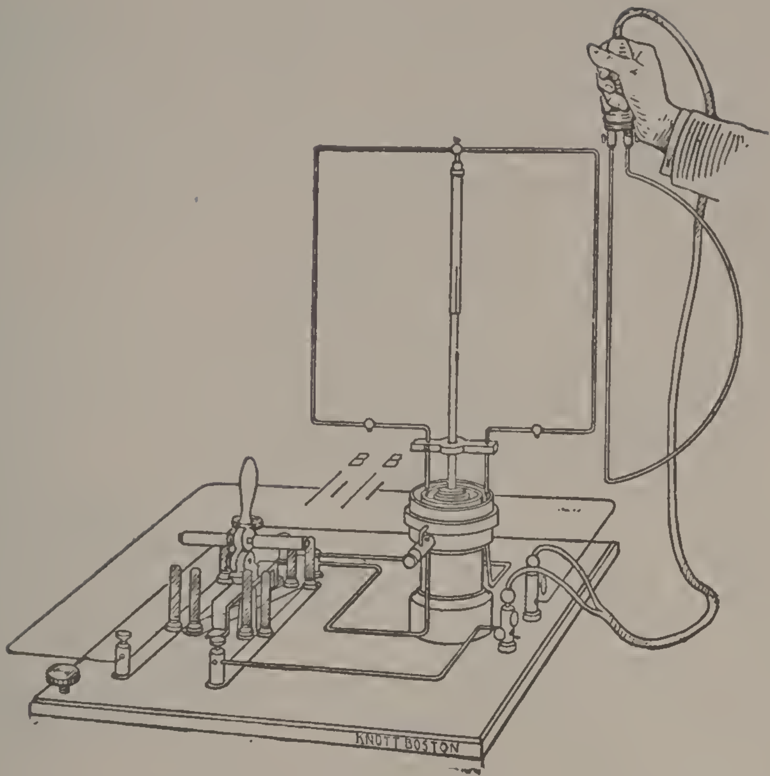


FIG. 28.—ATTRACTION OR REPULSION BETWEEN PARALLEL CONDUCTORS CARRYING CURRENTS.

outer coil will tend to set itself or move into a position parallel with the first or stationary coil. This movement is against a spring, hence if the deflection is measured, the current strength can be determined,

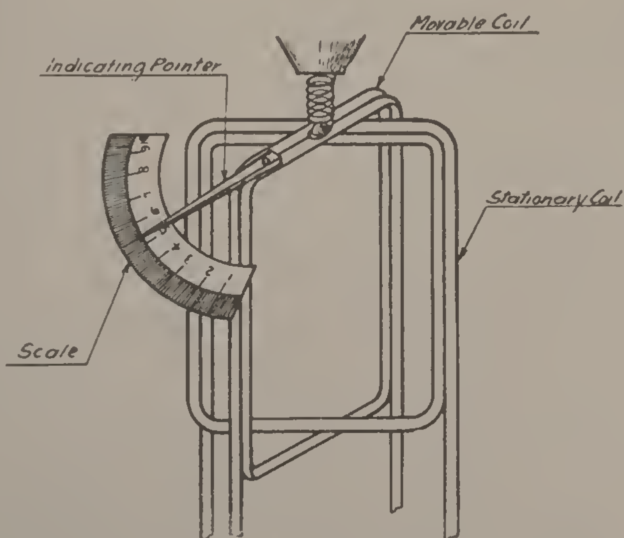


FIG. 29.—ELECTRO-DYNAMOMETER.

In order to tell exactly the amount of current flowing, it is necessary to measure and determine the number of amperes. The instruments used for this purpose are generally called **ammeters,** of which there are several types as follows:

1. Hot Wire
2. Electromagnetic
3. Moving Coil

Additional types are sometimes used on alternating-current circuits. These will be described later. In order to understand how an electric current can be measured with an ammeter, let us take up the different kinds and examine their construction:

Wires are heated by the passage of an electric current, and the larger the current the greater the amount of this heating. Most metals expand as they are heated, this expansion being proportional to the temperature of the wire — the higher the temperature, the greater the expansion. The **hot-wire ammeter** will be readily understood by referring to diagram shown in Fig. 30. The leads

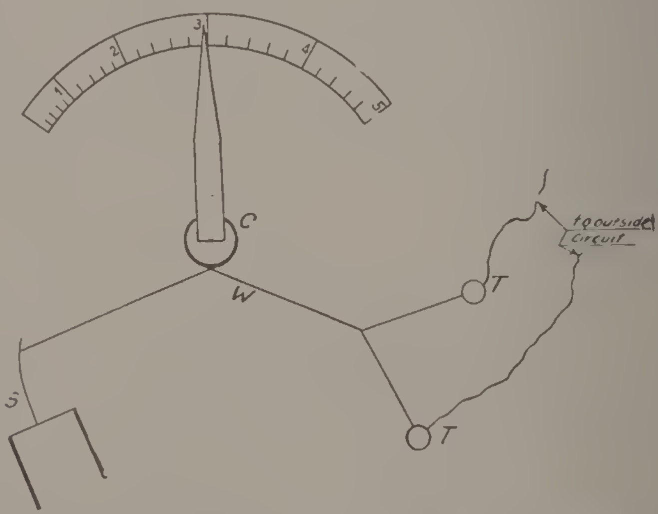


FIG. 30.—DIAGRAM OF HOT-WIRE AMMETER.

from the external circuit are connected to the two terminals, T and T. Between these two terminals is stretched a platinum-silver wire. To the middle of this platinum-silver wire is attached

another fine wire which is passed or wrapped around the cylinder *C* and thence to spring *S*.

If the current passes through the platinum-silver wire it becomes heated, and consequent expansion allows the spring *S* to pull the wire *W* towards the left and thus rotate the cylinder *C*, causing pointer to move across the scale. As the expansion of the platinum-silver wire is proportional to the amount of current flowing, the movement of the pointer will be correspondingly affected, and if the scale is correctly divided, the pointer will indicate the number of amperes in the circuit.

Hot-wire ammeters can be used on direct or alternating-current circuits equally well, and are especially adapted for high-frequency work in connection with wireless telegraph apparatus.

The **electromagnetic ammeter** is quite simple, but because it lacks sensitiveness and accuracy, is not very widely used. If the ends from the coil in Fig. 31 are connected to a battery or source of current, the plunger *P* will be sucked upwards. Likewise in Fig. 32, the plunger will be pulled or attracted in a downward direction, due to the magnetic attraction. This attraction depends on the strength of the current, which can be measured by the rotation of the attached pointer. This meter is suitable for use on either alternating or direct-current circuits. More than all others combined, the ones most used are the **"Movable Coil"** type of instrument.

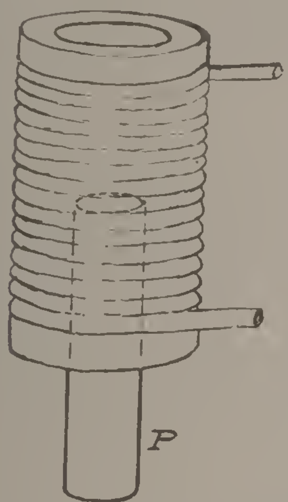


Fig. 31—Coil and Plunger.

If we have a coil, as shown in Fig. 33, mounted on an iron cylinder, and pass a current through it, north and south poles will be produced. Now if this coil and cylinder are pivoted and free to rotate,

when placed in a magnetic field as in *B*, they will tend to turn in the direction indicated. If the coil were mounted on a light frame of wood or some

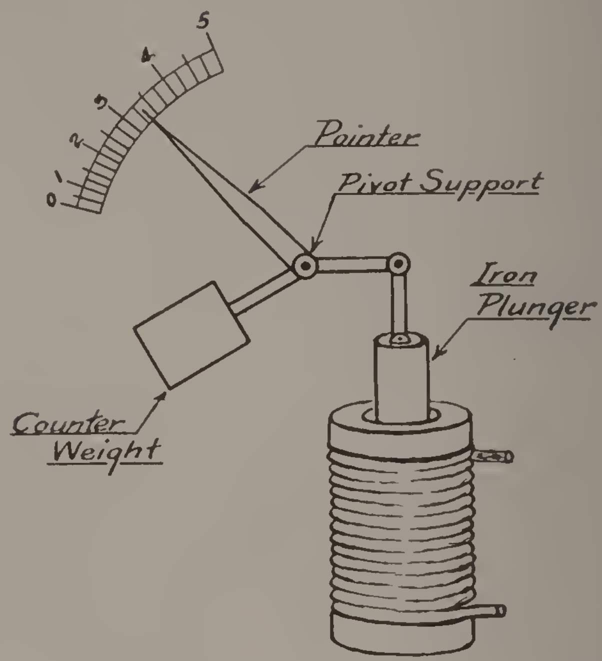
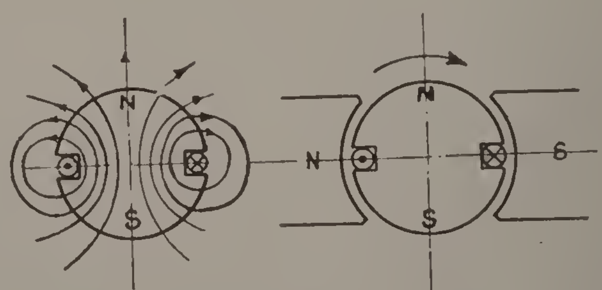


Fig. 32.—Electro-Magnetic, or Coil-and-Plunger Type, Ammeter.

similar material, instead of the iron cylinder, and then placed in the magnetic field, there would be a force, as before, tending to turn the coil — although not as strong as before.

A **moving-coil** type **ammeter** consists essentially of a permanent magnet, between the jaws of which



A Fig. 33. B

is a cylinder-shaped iron core. In the annular space between this iron cylinder and the poles of

the magnet, is a small rectangular coil wound on a light aluminum frame. This frame is held or supported by jewel bearings, allowing it to rotate in the space shown. The pointer is attached to the aluminum frame. A view of one of these instruments complete as manufactured by the General Electric Company is shown in Fig. 34. The parts

FIG. 34.—G. E. TYPE D2 MOVING COIL AMMETER.

are shown in Figures 35 and 36. Fig. 37 illustrates the moving element in position in an ammeter made by the Weston Electrical Instrument Company.

FIG. 35.—G. E. TYPE D2 AMMETER WITH COVER REMOVED.

Ammeters are always connected in series with the line as has been shown and the coils in ammeters are, generally speaking, of large wire and few turns. Ammeters, therefore, have very small resistance, and if connected across, rather than in series with the circuit, they will in most cases be ruined by the resulting short circuit and probably burn the man connecting it in circuit. The comparatively high voltage across the circuit is sufficient to force many times normal current through the low-resistance coils of the ammeter, burning and destroying the insulation, and ruining the instrument.

Fig. 36.—G. E. Type D2 Ammeter with Cover and Scale Removed, Showing Mechanism and Permanent Magnet.

Voltmeters, or instruments used to measure voltages, are connected directly across the circuit between the two main lines, on all circuits on which the potential does not exceed six or seven hundred volts. Voltmeters are constructed on exactly the same principles as ammeters, only the coils or windings used are of many turns of fine wire and offer a high resistance to the flow of current. In this way, when they are connected across the circuit,

only a small current is allowed to flow through the instrument windings. Sometimes, on circuits where the voltage is high, additional resistance coils are connected in series with the voltmeter, thus keeping the current down. These are called multipliers, as the voltmeter indication has to be multiplied by a constant to reduce to volts, when they are used.

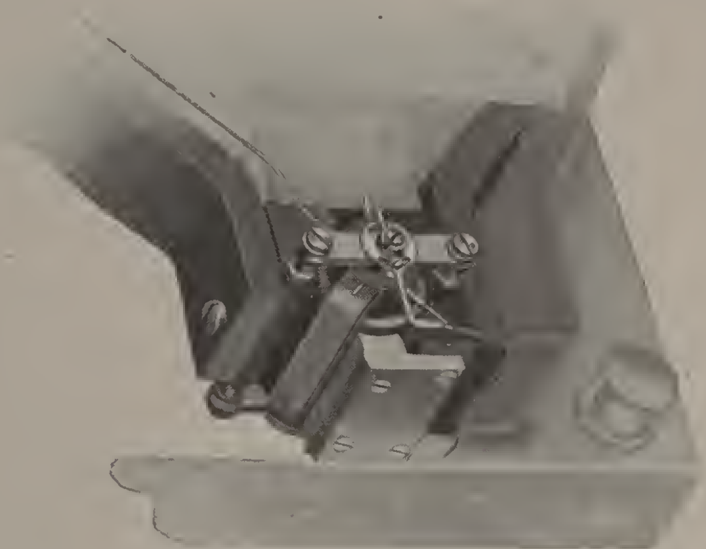


Fig. 37.—View Showing Interior of Weston Moving Coil Ammeter.

In order that an instrument may indicate accurately, it is necessary that the moving element move very freely. If this is not the case, and the meter is "sticky," small changes of current or voltage would not cause the needle to move correspondingly. The moving elements of high-grade instruments are pivoted and supported in jewel bearings, similar to the moving parts of watches. Sapphires and diamonds are used for this purpose.

These delicate bearings must be protected from vibration, or severe jolting, to insure perfect accuracy of operation.

CHAPTER V

OHM'S LAW

Explanations Showing Why This Law Holds True for Direct-Current Circuits — Resistance.

In the illustration, *P* represents an iron water-pipe and the distance from *E* to *O* is quite

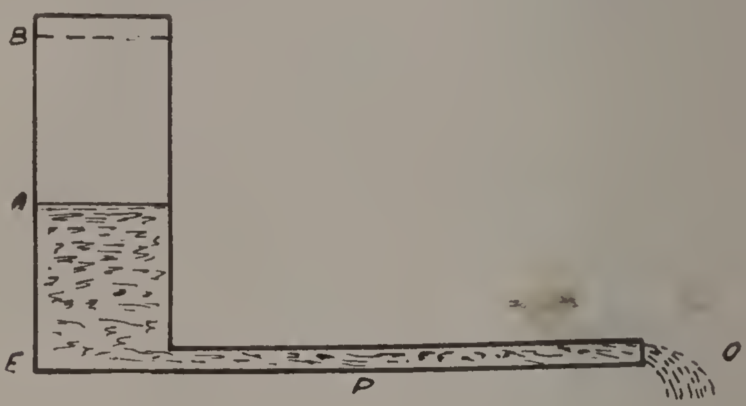


Fig. 38.

long, say for instance, a mile or so. *EA* represents a stand-pipe such as is used in many of our cities as a means of obtaining pressure on the Water Works System.

The amount of water in gallons per minute obtained at *O* will be proportional to the height of water in the stand-pipe, that is, *EA*. If the level or top of water is increased from *A* to *B*, making the column or height of water twice as high, the pressure exerted will be doubled and cause twice as much water to flow through the pipe. The flow is proportional to the pressure.

It is obvious that the amount of water emerging from the pipe at *O* depends directly upon

the size of the pipe *P*. The larger the pipe, the more water will flow, or if the pipe be made smaller, the amount of water obtainable will be less. The flow is proportional to the size of pipe.

The length of pipe will also affect the amount of water flowing; naturally, if the pipe is made longer it will offer more resistance to the flow and diminish the quantity issuing at *O*.

If the inside of the pipe is rough, it will offer more resistance to the flow of water than if it is smooth. A polished glass tube will let more water flow, with the same pressure, than a rough iron pipe of equal size. Thus, besides the pressure, the size and the length of a pipe, the flow of water through it is also affected by the interior condition of the pipe.

To sum up the above observations, it might be said that the flow of water depends upon the pressure and inversely upon the resistance offered to its flow. The resistance is dependent upon the following three conditions.

1. Size of Pipe.
2. Length of Pipe.
3. Material or Interior Condition of Pipe.

The passage of an electric current along a wire has many striking similarities to the flow of water in a pipe and is governed, to a certain extent, by similar laws. The amount of current which will flow along a wire depends, as with water in a pipe, upon two things: pressure and resistance. The resistance depends on the following:

1. Size of Wire.
2. Length of Wire.
3. Composition and Condition of Wire.

Of course in electrical work where we desire to transmit power and large currents for lighting purposes, it is best to have wires and conductors made of a material which will be strong and at the

same time conduct or allow the electricity to flow as easily as possible. Wires made of copper are most commonly used, as this metal has a very low resistance. The resistance of copper is less than that of almost any other material except silver, which is only a slightly better conductor than copper; and of course, silver would be too expensive to use in ordinary commercial work. Aluminum is sometimes employed, but for transmission lines one disadvantage encountered is the difficulty of joining it together or soldering it. Nearly all metals are conductors — even the human body will conduct current to a certain extent. The resistance of the different metals is taken up more fully later on.

There are many substances which will not conduct electricity, such as porcelain, marble, slate, glass, rubber, guttapercha and air. These are called non-conductors or insulators. For instance,

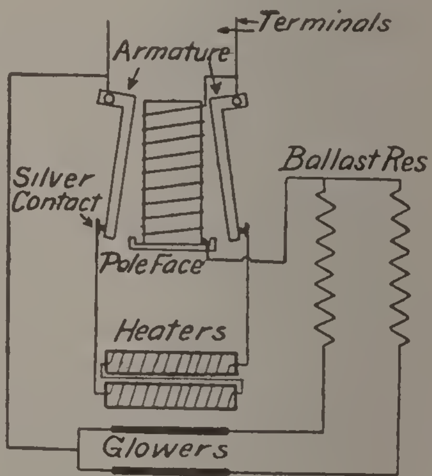


FIG. 39.—NERNST LAMP, EXTERIOR VIEW, AND DIAGRAM OF CONNECTIONS IN THE LAMP.

dry wood is an insulator but wood soaked with ordinary water will carry a current, due to the moisture it contains. Again, the glower used in the Nernst Lamp, when cold, will not conduct

electricity. This glower is usually made of a composition consisting of yttrium, magnesium and other substances, and has first to be heated before it will conduct the electric current. It is thus a nonconductor when cold and a conductor when hot.

As we have seen, the resistance a substance will offer to the flow of current depends on several conditions, such as size, length, material, temperature, etc. Although resistance is an abstract quantity, that is, one which cannot be seen or handled, nevertheless it can be easily measured and is expressed in a unit called the ohm.* If we say a certain wire has so many ohms resistance, a clear idea is at once gained of this property of the wire. Unless the resistance changes the temperature of a wire, it is independent of the amount of current flowing through it, and is practically a fixed quantity.

The current flowing in a wire or electric circuit is in accordance with the law which was discovered by Ohm, a German physicist. For direct-current circuits, **Ohm's law** is expressed as follows: Current in amperes equals volts divided by ohms. That is to say, that the number of amperes or intensity of current flowing in an electric circuit is directly proportional to the electromotive force, and also depends inversely upon the resistance offered to its flow. If we use the symbols, I, E and R to represent respectively the intensity of the current (in amperes), the electromotive force (in volts), and the resistance in ohms, we can write Ohm's law in any of the following three ways:

$$I = \frac{E}{R} \qquad E = RI \qquad R = \frac{E}{I}.$$

Thus of the three quantities, E, I or R, if we know any two, the third can be found.

* Definitions and values of the electrical units, Volt, Ampere, and Ohm, will be found in Appendix I.

Suppose we have a coil, as represented in Fig. 40, of a certain number of turns of wire of such a size that the resistance will be 10 ohms. If we connect this coil across an electric light circuit where

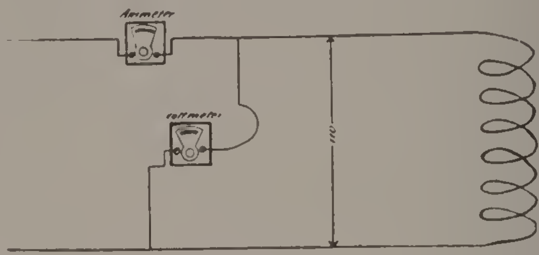


FIG. 40.

the pressure is 110 volts, the current that will flow, by Ohm's law (Form 1), will be as follows:

$$I = \frac{E}{R} = \frac{110}{10} = 11 \text{ amperes.}$$

On the other hand, if we know the resistance of the coil, and with an ammeter measure the current flowing, we can calculate the voltage on the terminals of the coil by using the second form of Ohm's law:

$$E = RI = 10 \times 11 = 110 \text{ volts.}$$

Again, if the voltage is measured with a voltmeter and the current measured with an ammeter, we can calculate the resistance of the coil by Form 3:

$$R = \frac{E}{I} = \frac{110}{11} = 10 \text{ ohms.}$$

CHAPTER VI

CIRCUITS AND RESISTANCE

Voltage Drop in Circuits — Series and Parallel Circuits — Methods of Determining Resistance.

Ohm's law will be made plainer by the following experiment with glass tubing as shown in Fig. 41.

If the faucet is wide open and water is poured in on the left through the funnel so as to maintain a level at A, the column AE will exert a pressure proportional to its height. This pressure will cause the water to flow to the right. It will be found that

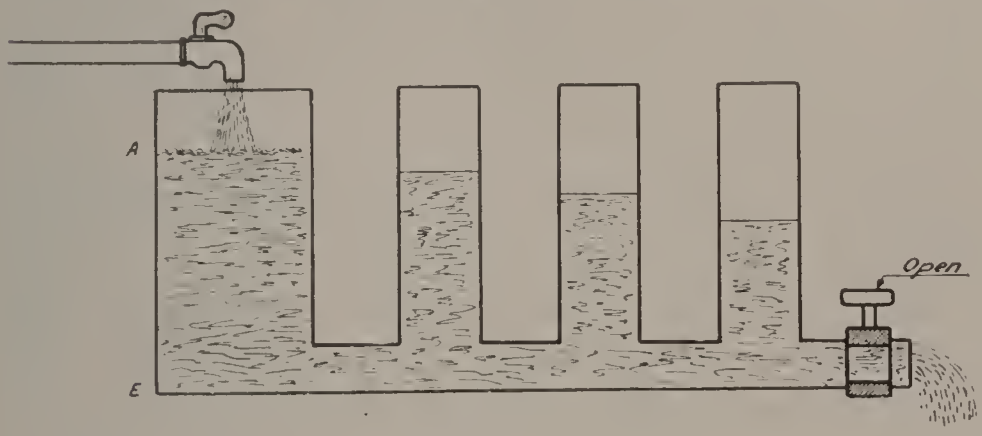


FIG. 41.

the water will rise to different heights in the four vertical arms, as shown, each lower than the preceding one to the left. This shows that as the water flows through the tube, it loses some of its pressure in overcoming the resistance, or in other words, there is a drop in pressure.

Fig. 42 represents a pump circulating water through a piping system. The water emerges from the pump under a pressure of, for instance, 11 pounds

per square inch. As it flows through the pipes, the pressure gradually decreases until, as the water returns to the pump, it is under practically no pressure. In other words, if we were to measure the pressure on the water in about the middle of the pipe at such a point as *M*, we would find that the pressure would be about 5.5 lbs. A little further on, such as at *N*, we might find the pressure to be 4.5 lbs., and again at *B* we might find the pressure to be 3.1 lbs. or even less. As the water flows through the pipes there is a gradual drop in pressure.

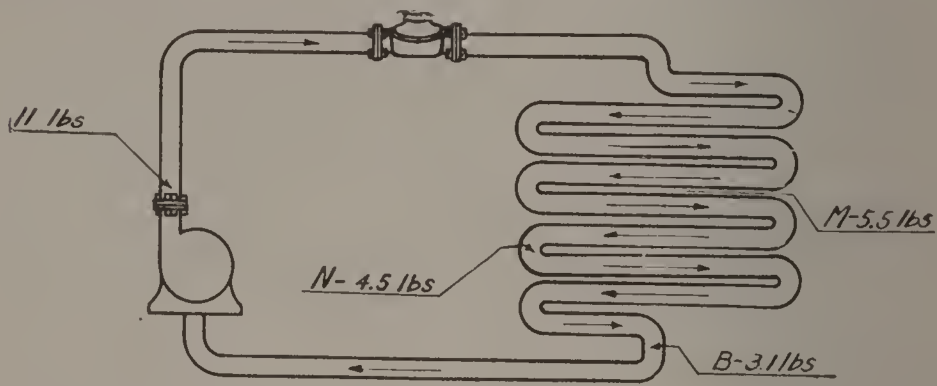


Fig. 42.

It is similar in an electric circuit as represented in Fig. 43; the direct-current generator is delivering current to an ordinary 16-candle power carbon filament incandescent lamp from a distance. The resistance of the lamp filament is 220 ohms while the resistance of each of the wires *AB* and *CD* is 5 ohms. It is necessary to have 110 volts pressure to force the necessary amount of current, $\frac{1}{2}$ ampere, through the filament of an incandescent lamp. If less current than this flows, the filament will not be heated to the proper brilliancy and the amount of light will be decreased. If the resistances, *AB*, *BC* and *CD* are in series, the total resistance through which the generator must force current will be the sum of these three $(5+220+5 = 230)$ which is 230 ohms. Now if we must have $\frac{1}{2}$ ampere flow in the circuit, the voltage necessary to force this

amount of current through 230 ohms can be found as follows:

$$E = RI = 230 \times \tfrac{1}{2} = 115 \text{ volts.}$$

In other words, the generator voltage or the pressure from A to D must be 115 volts. To force $\frac{1}{2}$ ampere through the 5 ohms, which is the resistance of the wire AB, will require a pressure of $2\frac{1}{2}$ volts; likewise $2\frac{1}{2}$ volts will be required to force $\frac{1}{2}$ ampere through 5 ohms, the resistance of wire CD.

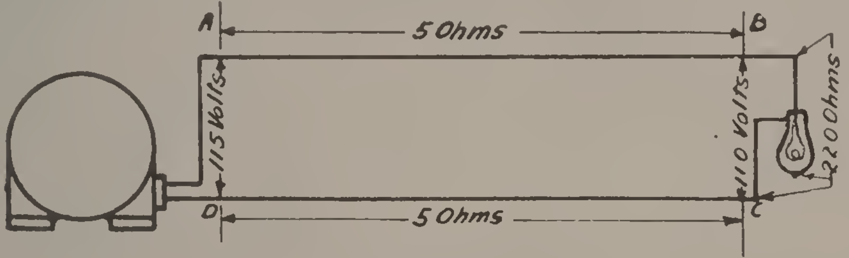


FIG. 43.

The three voltages from AB, BC and CD will be respectively $2\frac{1}{2}$, 110 and $2\frac{1}{2}$ volts and are called the voltage drop for each part of the circuit. The total sum of these drops will equal the generator voltage. This is true in all direct-current circuits. The sum of the drops from A to B and C to D is 5 volts, which will be the voltage drop in the lines or the pressure loss in overcoming the resistance offered to flow of current by the wires AB and CD.

While the generator is delivering 115 volts, there is only 110 volts being received or delivered to the incandescent lamp.

In Fig. 44 a direct-current generator is represented as delivering current to an ordinary carbon-filament incandescent lamp. Assume that the resistance of the wires AB and CD is negligible or

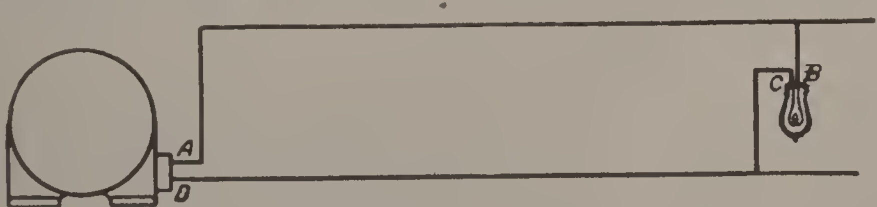


FIG. 44.

in other words, so small as to be inappreciable. If the generator is running at a speed that will give a pressure of 110 volts, ½ ampere will flow through the incandescent lamp, providing the resistance from B to C is 220 ohms.

Suppose we connect a second lamp in circuit, as indicated in Fig. 45. Providing the pressure between B and C remains 110 volts, there will now be 1 ampere flowing as indicated on the ammeter in the line. By connecting the two lamps as indicated we have given the current two paths in parallel. The resistance of each lamp is still 220 ohms, and

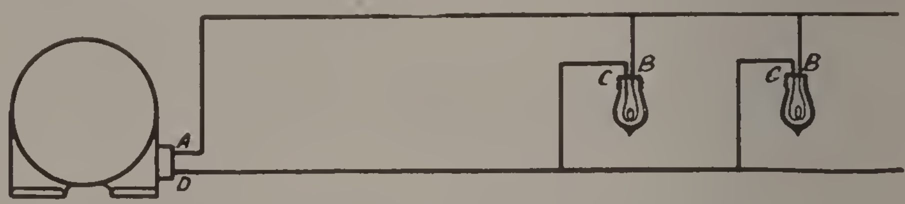


FIG 45.—TWO LAMPS IN MULTIPLE.

110 volts, the pressure between B and C, is sufficient to force ½ ampere through each lamp. Now while the resistance of each lamp is the same, the two lamps together have the same effect as though we had connected one lamp from B to C with a resistance of 110 ohms, that is, the effective resistance of the two lamps connected in parallel is one-half that of either lamp alone. By giving the current the two paths, we have made it just that much easier for the current to flow.

Fig. 46 represents a lamp bank with four lamps in parallel, or, as it is often called, in multiple. There will be ½ ampere flowing through each lamp, providing the pressure remains at 110 volts. The ammeter will now indicate 2 amperes. Thus, the effective or combined resistance of four lamps in parallel is even less than two lamps in parallel. This is proved by the fact that 110 volts cause 2 amperes to flow in place of 1 ampere. As the current is increased, the resistance must be less. The

more lamps connected in multiple, the more paths are offered for the flow of current and the resistance becomes less in proportion.

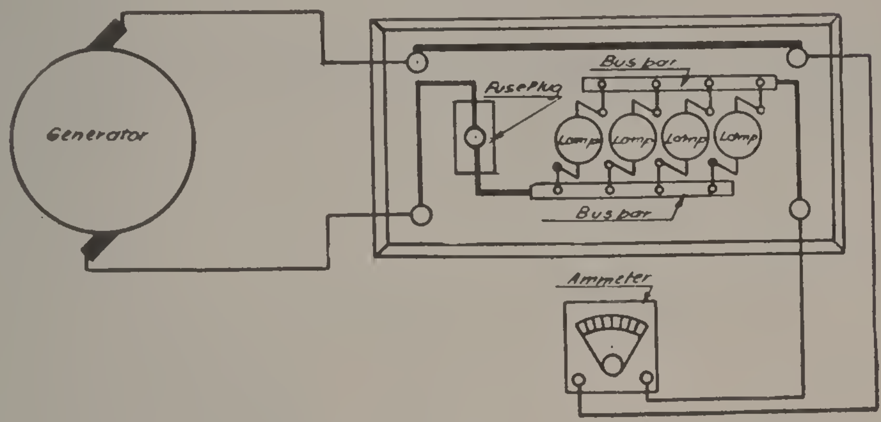


FIG. 46.—LAMP BANK, WITH FOUR LAMPS IN MULTIPLE.

If connected in parallel, the resistance of two lamps is one-half as much as that of one lamp, and the resistance of four lamps is one-fourth that of one lamp, and so on.

Suppose on the other hand, we connect two lamps, as shown in Fig. 47, in such a manner that the current passes first through one lamp then through the other. The resistance offered to the flow of current between the points *B* and *C* is twice as great as though only one lamp were connected, as in Fig. 44. If the resistance is twice as great and the voltage between *B* and *C* is 110 volts, the current will be one-half as much as in

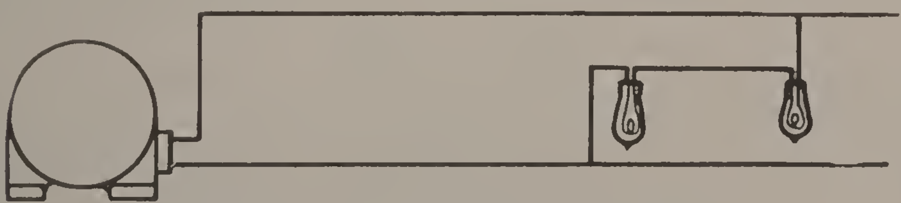


FIG. 47.—TWO LAMPS IN SERIES.

the arrangement represented by Fig. 44. With the two lamps connected in series, the total resistance would be 440 ohms and the current $\frac{1}{4}$ ampere. When connected in this manner, the lamps are said to be

in series. In a series circuit it will be noted that the same current flows in all parts.

If we go a step further and connect four lamps in series between points *B* and *C*, the total resistance will be 880 ohms and the current can be calculated by dividing the voltage by the resistance, or in other words, $110 \div 880$ would be $\frac{1}{8}$ ampere which will flow. The resistance of four lamps is four times as great as that of one lamp, consequently, the current is one-fourth as much.

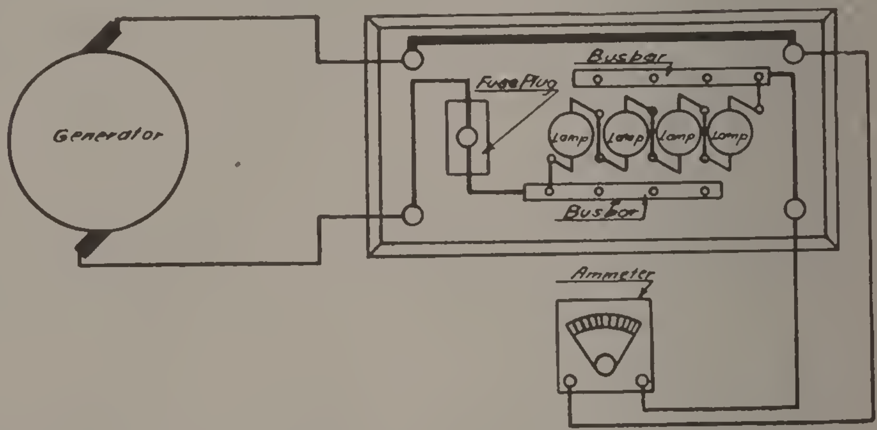


FIG. 48.—LAMP BANK, WITH FOUR LAMPS IN SERIES.

On trolley circuits where the usual voltage is 550, five 110-volt lamps are sometimes connected in series — as there will be approximately one-fifth of the total drop in each lamp, or 110 volts, there will be $\frac{1}{2}$ ampere flow, which is the proper current. If only one lamp was connected across 550 volt mains, five times normal current would flow, burn the filament and ruin the lamp.

There are several methods of **measuring the resistance** of conductors or substances. One of the most widely used is known as the "**Drop of Potential**" method, and is a very convenient way in which to determine the resistances of coils or windings. The resistance can be determined by measuring the voltage necessary to force a certain current through the coil. The instruments necessary are an ammeter and a voltmeter.

Another common method or instrument used to measure resistances is the **slide-wire bridge,** illustrated in Fig. 49, and may be more easily

Fig. 49.—Slide-Wire Bridge.

explained by reference to Fig. 50, which is a diagram of the ordinary **Wheatstone bridge**. The resistance of the coil *R* is known, and *GS*1 and *GS*2 are two adjustable resistance coils. *X* is the unknown resistance. Current from the batteries flows to *A*, where it divides and flows through the two paths *ABD* and *ACD* in inverse proportion to their resistance. Now there is a certain potential at *A*, a certain drop in the two paths, and a certain resulting potential at *D*. There is a certain drop from *A* to *D* — as the portion of the current flows through the path *ABD*, there is a gradual drop to the potential at *D*. Likewise there is a gradual drop in potential in the path *ACD* from *A* to *D*. At certain points, such as *C* and *B*, the potential is equal, if the *GS*1 and *GS*2 have been adjusted.

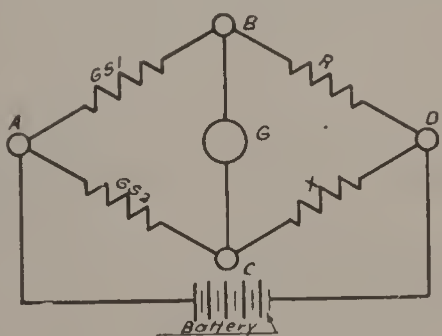


Fig. 50.—Wheatstone Bridge Diagram.

Consequently if a galvanometer is connected between *B* and *C*, as the potential is the same, no current will tend to flow through the galvanometer and hence there will be no deflection of the needle. When

in this condition the ratio of $GS1$ to R is equal to the ratio of $GS2$ to X. Expressed in proportion:

$$GS1 : GS2 :: R : X$$

$$\text{or } \frac{GS1}{GS2} = \frac{R}{X}$$

If $GS1$, $GS2$ and R are known, X can be easily found, as

$$X = \frac{GS2 \times R}{GS1}$$

While in effect the same as in Fig. 50, the slide-wire bridge is in reality shown diagrammatically in Fig. 51. The same reasoning applies as in Fig. 50.

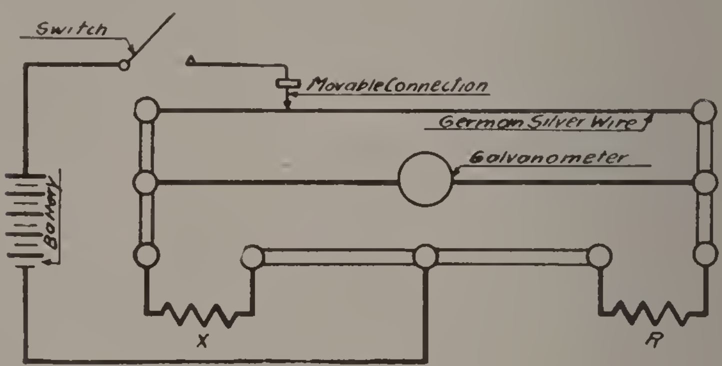


Fig. 51.—Diagram of Connections of the Slide-Wire Bridge.

If the size of a wire is known, its resistance can be found in the wire table which is taken up later.

CHAPTER VII

ENERGY

Power — Explanation of: Watt — Kilowatt — Watt-Hour — Kilowatt-Hour.

If we wish to measure the power obtainable from a river or a waterfall it is necessary to know the cross section of the stream flowing and the pressure available at the water wheel. If the head of water is increased to twice its former height, the stream will exert a proportionately greater pressure on the water wheel, due to the increased velocity it will acquire in falling through the greater distance. If the cross section of stream is doubled the turning effort on the wheel will also be doubled. Hence the work done by the stream depends on both the amount of water flowing and the velocity or pressure with which it strikes the water wheel.

Work is the expenditure of **energy,** and such actions as turning waterwheels or lifting weights represent work done. A unit called the foot-pound is the amount of work done when one pound is raised through a distance of one foot. Thus raising one-half pound through a distance of two feet would be one foot-pound.

The formula is:

Foot-pounds = weight (in lbs.) × distance (in ft.).

If a waterwheel is being turned, work is being done at a certain rate, that is, so many foot-pounds per second or so many foot-pounds per minute. The **power** or rate at which work is being done is expressed in foot-pounds per minute or second or in the unit called **Horsepower.** The horsepower is equivalent to 550 foot-pounds a second or 33,000 foot-pounds a minute. It was first used by James

Watt, who was made famous by his improvements of the steam engine. In his time the collieries and mines in England used horses for hauling and hoisting. When he substituted his engine, the inquiry was: "How many horses will it replace?" Or in other words: "How many horsepower will the engine deliver?" Thus a horsepower is supposed to represent the rate work is capable of being done by a very strong horse. The colliery horses were very large and strong and as the horsepower was based on their strength and capacity, it is above the power of the ordinary horse, for any appreciable length of time.

By the same reasoning, the power derived from an electric circuit is dependent on the pressure or voltage, as well as the current or amperes. The unit of power is the **watt** (named in honor of James Watt) being one ampere flowing under a pressure of one volt. To obtain the watts or power in any direct-current electrical circuit, multiply the volts by the amperes, their product being the watts.

To light an incandescent lamp requires a certain amount of power. The ordinary 16-candle power carbon lamps have a filament of 220 ohms resistance. If the lamp is placed on a 110-volt circuit, $\frac{1}{2}$ ampere will flow through the filament. The watts $= E \times I = 110 \times \frac{1}{2} = 55$.

If two of these lamps are placed in multiple on the 110-volt circuit, the total current is one ampere and the watts $= E \times I = 110 \times 1 = 110$.

On the other hand, suppose these two lamps are placed in series on a 220-volt circuit, the two filaments in series will offer a combined resistance of 2×220 or 440 ohms and the current is $\frac{1}{2}$ ampere. The watts $= 220 \times \frac{1}{2} = 110$, or, in other words, the watts are the same whether the lamps are in series or multiple — this is as it should be as the light and the energy expended or work done is the same in either case.

Three ways to write formula for watts in a circuit are:

$$W = I \times E$$
$$W = I \times IR = I^2R \qquad (\text{as } E = IR)$$
$$W = \frac{E}{R} \times E = \frac{E^2}{R} \qquad (\text{as } I = \frac{E}{R})$$

The prefix "kilo" means thousand, hence **kilowatt** means a thousand watts, often used for convenience, as the watt is too small for many calculations in practice.

If one consumer uses or lights two incandescent lamps for two hours and another consumer uses four lamps for the same length of time, it is obvious that the latter has used twice as much electricity as the former, and should pay twice as much. Likewise, if one man uses two lamps for two hours and a second has two lamps lighted for four hours, the quantity used in the second case is twice as great as in the first. It is equally important, in charging a customer for the quantity of electricity consumed, to consider the length of time as well as the number of lamps or amount of current required.

The unit commonly used and in which the familiar integrating wattmeters register on their dials, is the **kilowatt-hour.** It is the quantity of electricity represented by the use of one kilowatt for one hour. Other units sometimes used are watt-seconds, being one watt for one second, and watt-hour, being one watt for one hour.

Suppose, for instance, a man had 10 incandescent lamps in his store, each taking ½ ampere at 110 volts. They would consume 55 watts per hour per lamp and 10 lamps would consume 550 watts. If the lamps were lighted 5 hours per night, they would consume 5 times 550 which would be 2,750 watt-hours or 2.75 kilowatt hours. If this customer's rate from the Lighting Company is 16 cents per kilowatt hour, his nightly bill would be 2.75 times .16 which would be 44 cents.

CHAPTER VIII

HEATING

Equivalent Values of Electrical, Mechanical and Thermal Units and the Interchangeability of Different Forms of Energy.

If a boat could pass through the water without meeting with any resistance it would require no effort to keep it in motion, but a boat in the water, or a wagon on land, or any moving object, meets and has to overcome friction, or in other words, the resistance offered to its motion: For this reason, to move objects and keep them in motion requires expenditure of energy. When substances are rubbed together and there is friction, they become heated; this heat is the form or way in which the energy used in overcoming the friction is manifested. The rougher the substances and the more rapidly they are rubbed, the greater will be the quantity of heat produced, which is only natural, as more energy is used.

As electricity flows along a wire from particle to particle, the resistance offered to its flow is similar to friction. In overcoming this resistance and maintaining the flow of current, energy is expended which causes the wire to become heated.

It is self-evident that more energy will be required to force a certain amount of current through a wire of high resistance than through one of low resistance. Thus the conductor of high resistance, on account of the greater amount of energy expended, will be heated to a higher temperature than will the wire of low resistance. Thus the filaments

of incandescent lamps are very small in diameter and made of carbon composition or of metal, such as tungsten, and have a very high resistance. The amount of energy expended in forcing current through the filaments is converted into heat, the quantity of which is sufficient to cause the filament to glow.

If a wire, while comparatively cold, is connected to a source of current, the temperature will rise, rapidly at first, then slower and slower until finally the temperature reaches a constant ultimate figure. At this point, the heat is being dissipated by radiation at the same rate as received by the wire. Radiation of heat depends largely on the outer surface of the wire. The larger the wire, the cooler it will be with a certain current passing, due to the increased surface exposed.

At first sight it might seem that the **heat** in a wire would be proportional to the current flowing, but it is in reality **proportional to the square of the current,** that is, to the current multiplied by itself. If the current flowing in a wire is doubled, the heat is four times as great. If the current is made three times as large, the heat is nine times as great. This can be proved mathematically by the fact that the heating in a wire depends upon the energy expended or the watts lost in a wire. The watts equal the product of the current flowing and the volts drop or pressure required to force the current through the wire, and can be expressed as follows:

$$\text{Watts} = EI = RI \times I = RI^2 \quad (\text{as } E = RI).$$

This will be more readily understood if we consider an experiment with a number of cells. Suppose we have a cell from which current is being passed through a coil. If we connect two cells in series, approximately twice as much current will be passed through the circuit. Now as twice as much current is flowing through each individual cell as in the first case, there will be four times as

much zinc consumed and the energy furnished the circuit will be four times as great while the current has only been doubled. The heating effect of the current flowing through the coil will likewise be four times as great.

If a coil of wire is immersed in a tank of water, and a certain current passed through the coil for a definite period of time, the temperature of the water will rise a certain amount. If the current is doubled and allowed to flow for an equal period of time, a thermometer, placed in the water, will show that the heat is four times the original temperature.

Platinum is very infusible, being practically unaffected by very high temperatures. For this reason, currents can be passed through a platinum wire until it is quite hot without melting or fusing it. Therefore, platinum wires are often used in blasting work for igniting the charges; or under water, torpedoes can be exploded at will by the operator from a distance away on land. Also steel rails are welded together by passing an electric current from one to the other and causing them to get red hot at their junction. Electric cooking devices depend for their heating upon a coil of wire which is made red hot by the passage of an electric current.

We, of course, read the temperature of the air in a room by thermometers, but this merely tells us how hot the air really is; it does not tell us how much heat there is. The quantity of heat depends on the size of the room as well as the temperature. Obviously if one room is twice as large as another it would require twice as much heat to keep the larger room warm in winter as would be required for the smaller.

The unit by which heat is measured in this country is the British Thermal Unit, often abbreviated and called B.T.U. It is the amount of heat required to raise one pound of water from 39 to

40° on the Fahrenheit thermometer. It is approximately the amount of heat necessary to raise one pound of water 1° Fahrenheit. In France or countries where the Metric System of measurement is used, and water is measured, not in pounds but in kilograms, instead of using the Fahrenheit thermometer, the Centigrade thermometer is used and the unit of heat with the metric system is called the Calorie. It is the amount of heat necessary to raise a kilogram of water from 0 to 1°C. In this country, in recent years, the Centigrade thermometer, on account of its simplicity and other advantages over the Fahrenheit, has come into universal use in scientific and engineering work. They are both described later on.

Thus summarizing, we see there are several kinds or forms of energy in which we are interested: To operate a motor requires electrical energy, and we obtain mechanical energy from the motor. When wires are heated there is thermal energy, and as a cell supplies current we might say there is chemical energy being changed to electrical.

We have said electricity is one form of energy, and mechanical motion or power represents energy, only in another form. Thus lifting weights and turning water wheels means the expenditure of mechanical energy, which is measured in foot-pounds. When incandescent lamps are lighted or motors operated it also means consuming power, or in this case, electrical energy, which is measured in watts. If both foot-pounds and watts, or horsepower and kilowatts, are merely units used to measure different forms of energy; if the different forms of energy can be changed or transformed one to the other—the units likewise must be capable of interchangeability.

This is true, and experiments and calculations show the various units to have equivalent values as set forth in the accompanying table.

UNIT	APPROXIMATE EQUIVALENT VALUES
1 H. P.	550 Foot-lbs. per Second 33,000 Foot-lbs. per Minute 746 Watts .746 Kilowatts 42.42 B. T. U. per Minute 10.689 Calories per Minute
1 K. W.	1,000 Watts 1.34 Horsepower 56.84 B. T. U. per Minute 14.323 Calories per Minute 737.3 Foot-lbs. per Second 44,240 Foot-lbs. per Minute
1 B. T. U.	.252 Calories 778 Foot-lbs.
1 Calorie	3.97 B. T. U. 3088 Foot-lbs.

CHAPTER IX

GENERATION (MECHANICALLY) OF ELECTRICITY

Induction — Cutting of Lines of Force.

To generate means to make, and a generator is something that produces or generates. This chapter deals with the principles applying to the mechanical generation of electricity, and the following chapters take up commercial generators which utilize these principles.

As previously explained, a conductor carrying current is encircled by magnetic lines of force. In

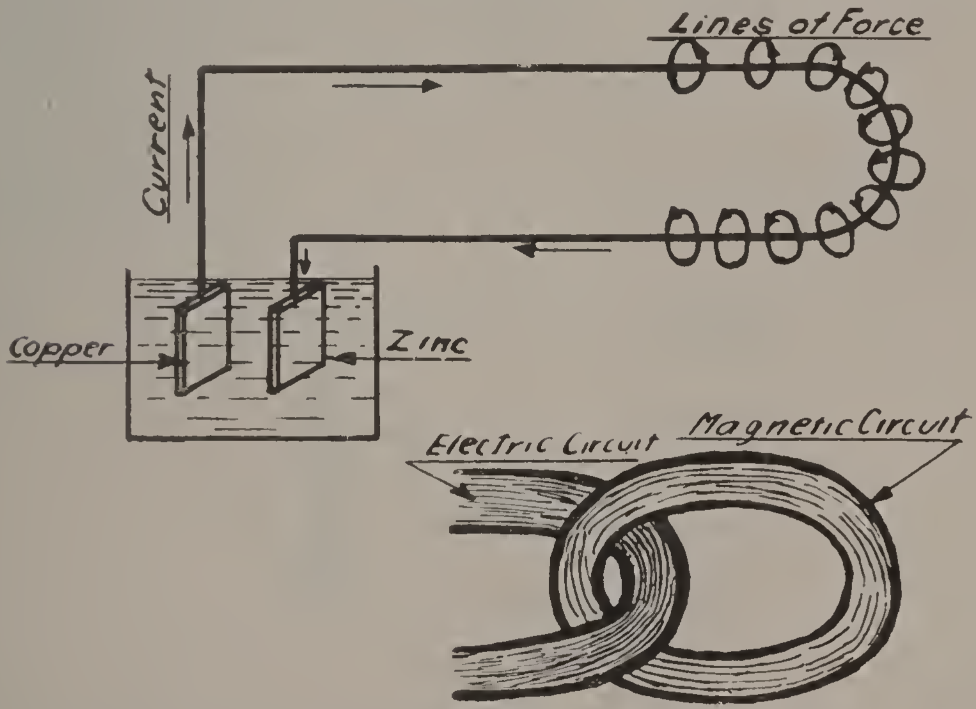


FIG. 52.—INTERLINKAGE OF ELECTRIC AND MAGNETIC CIRCUITS.

other words the electric current and the lines of force are interlinked, just as two links of a chain are

connected together. No matter how small, it is impossible for any electric current to flow without producing some of these magnetic whirls, while the larger the number of amperes, the greater the number of lines produced, as the number of these interlinkages is dependent upon the current strength. It will be noticed also that these magnetic lines are

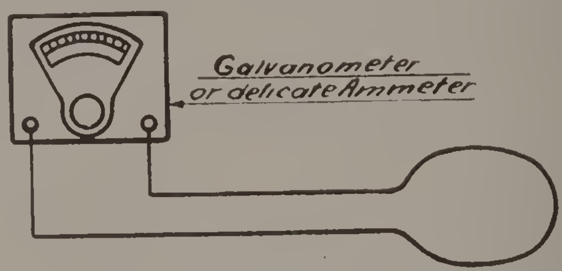


FIG. 53.

in a plane at right angles to the direction of flow of current. These observations might be summed up in the following: **An electric current is always interlinked with magnetic lines of force and at right angles to them.** These whirls are produced by the flowing current in a wire. On the other hand, an electric current can be produced and made to flow in the wire or circuit by the action of magnetic lines,

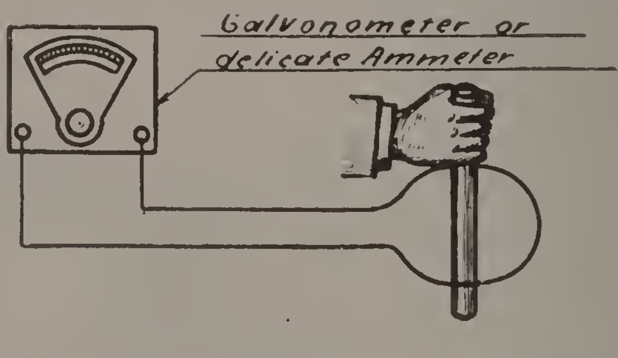


FIG. 54.

under certain conditions. To investigate this phenomenon and see to what limits this statement will hold, let us proceed as follows: Suppose the ends of a loop of wire are connected to a milli-ammeter, as shown in Fig. 53. If a strong bar magnet is

plunged into the loop, the magnetic lines encircle the conductor and the ammeter needle will be suddenly deflected. As there is no connection to any outside source of power, we might draw the conclusion that as the lines encircle the conductor, a voltage is induced which causes the current to flow. To obtain

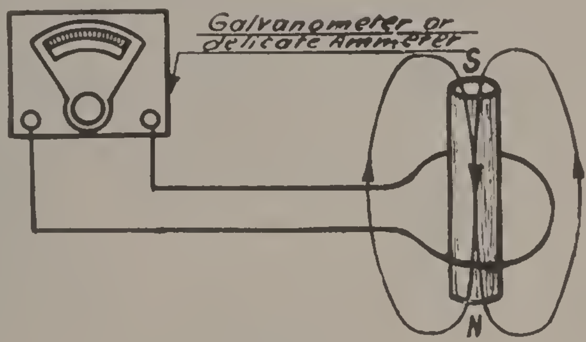


Fig. 55.

good results the ammeter used must be very sensitive as the currents induced in this way are very small. In some cases where the magnet is weak or the moving element of the ammeter a little hard to move, it will be better to use a galvanometer.

If the magnet has been plunged into the loop, until midway, half in and half out, and is then held in this position, it will be seen that the needle comes to rest and returns to zero almost instantly after the motion of the magnet is stopped. Then, if the magnet is quickly pulled out, the needle is again

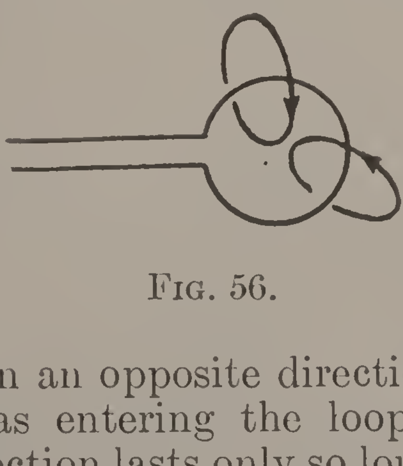


Fig. 56.

deflected, but in an opposite direction to that when the magnet was entering the loop. However, as before, the deflection lasts only so long as the magnet is passing the conductor. We might then further

state that while a current can be induced in the loop by means of magnetic flux, it is only while the number of lines encircling the conductor are changing, either increasing or diminishing, that a voltage, and consequently a current, is induced. While the number of lines is constant there is no effect. This will be made still plainer by the following discussion and experiment:

If a stiff copper rod, with its ends connected by flexible leads to a galvanometer or an ammeter, is

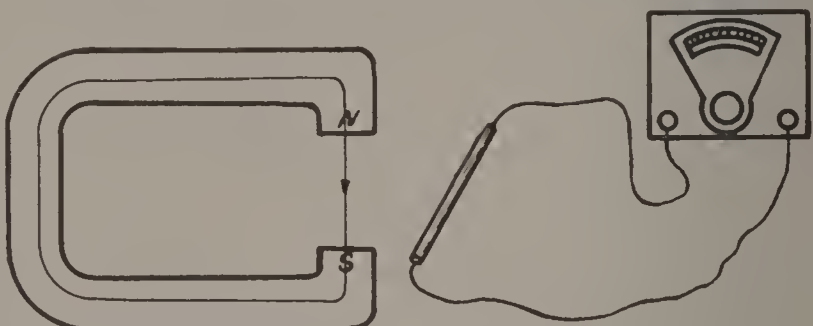


FIG. 57

suddenly thrust between the jaws of a permanent horseshoe magnet, the movement will cause the rod to cut across the lines of force, and as it enters the central part of the magnet the electric circuit or coil of one turn has interlinked with the magnetic cir-

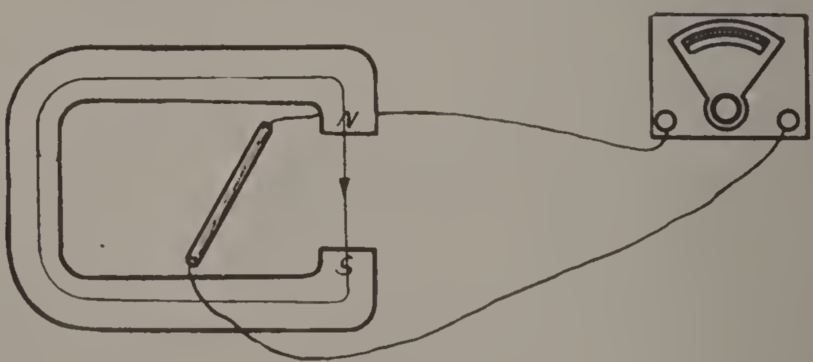


FIG. 58.

cuit. Due to this interlinkage, or encircling of the copper by the lines of force, the current is caused to flow. But the needle of the ammeter is deflected or

indicates a flow of current only so long as the number of the interlinkages is increasing — or in other words, as long as the conductor is cutting across the magnetic field.

After the rod passes the jaws of the magnet, the number of interlinkages becomes constant, and the galvanometer needle returns to zero. Again if the rod is quickly drawn out through the jaws, the needle will indicate the flowing of a current. And also if the motion of the rod is made more rapid, the deflections of the needle become proportionally greater.

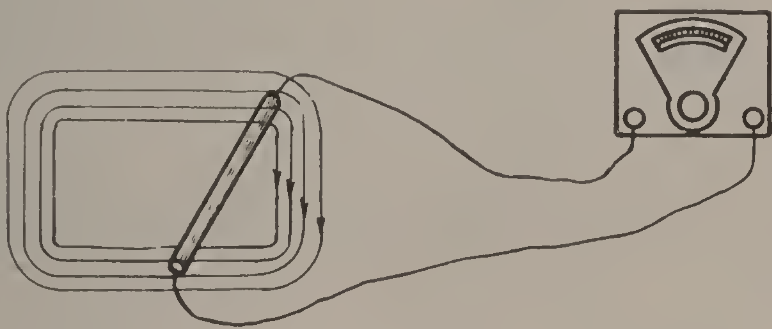


Fig. 59.

The conclusion can be drawn that if there is a relative motion between a magnet and an electrical circuit, so as to cause a variation in the number of interlinkages, either increasing or decreasing their number, a voltage will be induced that will be proportional to the rate of change in the number of interlinkages.

Either the magnet or the wire may be the moving body, or both might be moved. It has been ascertained by extensive experiments that for every 100,000,000 interlinkages around a conductor per second, there is one volt induced. Thus if we know the strength of the field and the time required for the conductor to cut through or interlink with it, the induced voltage can be easily calculated. For instance, suppose it takes one second for the rod to pass between the jaws at a uniform rate. If there

are 50,000,000 lines of force crossing from the north to the south pole, and these are cut by the conductor, the interlinkages are 50,000,000, and one-half volt will be induced. If the resistance of the rod, ammeter and flexible leads is assumed to be one-half ohm, this voltage will cause one ampere to flow while the motion of the rod is taking place, as the voltage is induced only so long as the motion continues.

As the rod is moved and the current flows, there is a force or reaction opposing its motion. If the magnetic field is strong and the conductor moved rapidly, this reaction will be quite perceptible. In moving the conductor and overcoming this force we do work, and the energy thus supplied is changed into electrical energy.

The direction in which the induced current flows is always definite, and has a certain fixed relation to the direction of the motion and the lines of force.

Fig. 60.

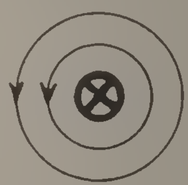


Fig. 61.

Lines of Force passing around a Conductor in a Clockwise Direction Induce Current Toward the Observer, and Vice Versa.

If lines of force are passed around a conductor which is at right angles to the plane of this paper, in a clockwise* direction, the voltage induced is such as will tend to make the current flow upwards towards the reader, and when whirls are in a counter-clockwise* direction, the induced current flows away from the observer or downwards through the paper.

This relation can be expressed by the following: If the fingers of the left hand are partly closed, so as

* Clockwise,— in the same direction as the motion of the hands of a clock. Counter-clockwise,— in the opposite direction.

to encircle the conductor, with the finger tips pointing along the magnetic lines, the thumb points in the direction induced current will flow. This is

FIG. 62.—RULE TO DETERMINE DIRECTION OF INDUCED CURRENT. (LEFT HAND.)

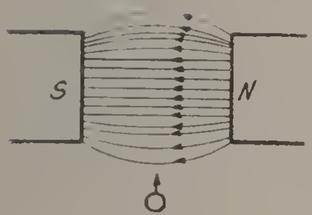


FIG. 63.

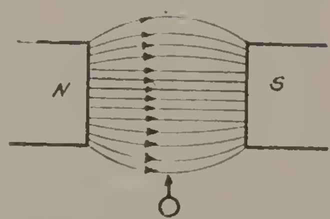


FIG. 66.

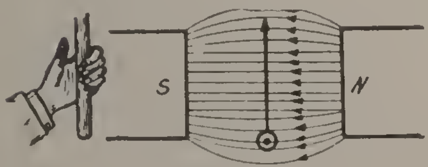


FIG. 64.

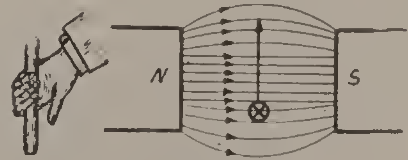


FIG. 67.

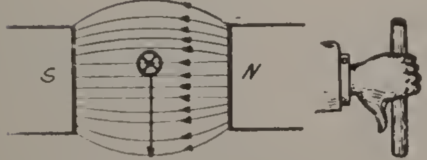


FIG. 65.

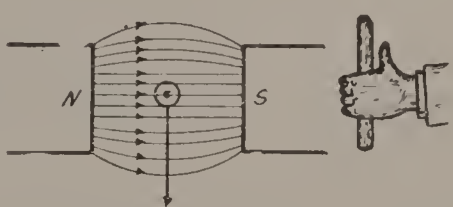


FIG. 68.

similar to the **rule** given in Chapter III for the determination of the direction of the whirls or lines **produced by a current,** and where the **right** hand was used, while here the whirls might be said to induce the voltages and thus **produce the current,** and the **left** hand must be used.

The following explanation will make plainer the somewhat special and very common application of this rule, where a conductor is being moved across a magnetic field and the greater part of the magnetic circuit is not shown.

In Fig. 63 practically all of the lines are passing from right to left over the approaching conductor, in which as yet no voltage has been induced.

In Fig. 64 the conductor has moved upwards, cutting through a certain number of the lines.

To calculate the induced voltage it is only necessary to know the number of lines actually cut through and the time taken. Provided there is a complete circuit offering a path for the current, we can easily determine its direction of flow even though all of each magnetic line is not visible, as the portion in sight is sufficient. Applying the rule, with the left hand, as shown in Fig. 64, encircling the conductor, point the finger tips in the direction of the lines of force just cut — the thumb will indicate current flowing upwards towards the observer.

After the conductor has passed through the field cutting all of the lines, suppose it is brought to rest and then drawn downwards through the field, as in Fig. 65. The left hand must be turned upside down in order to allow the finger tips to point in the direction of the lines just cut. The induced current will flow downwards away from the reader. In other words — **if the direction of motion is reversed, the induced current will flow in the opposite direction.**

Now let us suppose the field magnet poles are exchanged (see Fig. 66), and the conductor is again

approaching. In Fig. 67 the lines cut are going from left to right underneath the conductor, and as the left hand must always be used, to point the finger tips in this direction it is necessary to hold the hand in the position shown. It will be noted that the direction of the induced current here is opposite to that in Fig. 64, for although the motion is the same, the magnetism is in a different direction. Also after the conductor has passed through the field if it is again drawn downward the current induced will be as indicated by Fig. 68.

From these figures it will be seen that a reversal in either the motion or the direction of the lines of force will cause, likewise, a reversal in the direction the induced voltage will tend to make current flow.

CHAPTER X

DEVELOPMENT OF GENERATORS OR DYNAMOS

Applications of Principles of Generation.

The wire described in the previous lesson, Figs. 57, 58 and 59, if moved rapidly back and forth, in the jaws of the magnet, would produce a current whose strength would be continually changing and the direction of which would alternate with each change in the motion. That is to say, the current would flow in the wire first in one direction and then in the other.

Instead of moving the conductor back and forth in a reciprocating motion a much simpler and better construction would be to bend the wire around in a **coil** as shown in Fig. 69 and mounted in some way

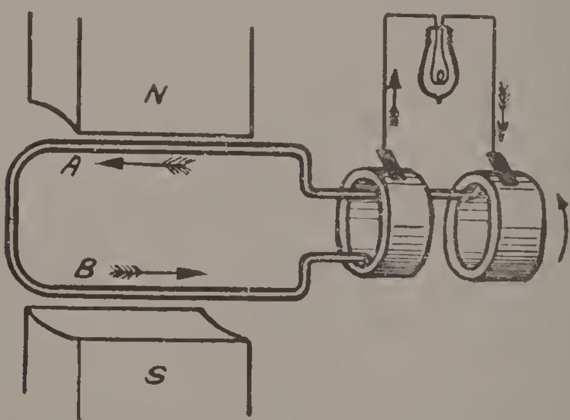


FIG. 69.—SIMPLE ALTERNATOR.

FIG. 70.

on a central axis or shaft so as to allow rotation as indicated by the arrow. Connect the ends with two **rings** mounted side by side but insulated from the shaft and each other.

In the position shown in Fig. 69, the sides of the coil will be cutting lines of force as represented diagrammatically by Fig. 70. Suppose the coil be rotated in a clockwise direction viewed facing the rings, from the right-hand side of Fig. 69, and indicated by arrows in Fig. 70. By rule in Chapter IX, there will be an induced voltage tending to make current flow away from the observer in the top wire and towards the observer in the bottom one.

There are two springs or brushes, one bearing against each of the **collector rings.** By this means current is lead to the outside circuit and the direction of its flow is indicated by the feathered arrows.

A quarter of a revolution later the conductors or the sides of the coil will enter a neutral region and for an instant the motion of each conductor will be

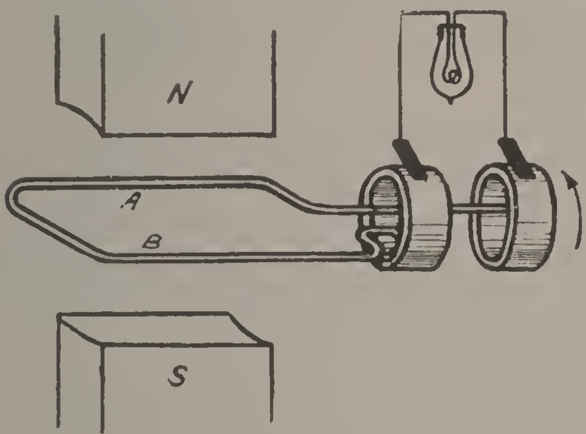


FIG. 71.

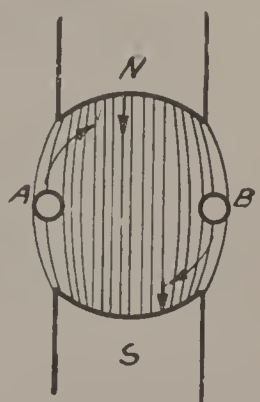


FIG. 72.

along and parallel to the lines of force. At this instant, illustrated in Figs. 71 and 72, the number of interlinkages is not being changed; the voltage induced is zero and therefore the current, unless influenced by other means, is zero. As the motion continues, both *A* and *B* commence to cut across the lines of force, at first slowly, then more rapidly, until the rate of change of interlinkages becomes a maximum again in the position shown in Figures 73 and 74. This causes voltage to be induced proportionally, and consequently, a current. But this current flows

in an opposite direction to that illustrated in the first case, Fig. 69, as *A* and *B* have changed places, or in other words are now cutting through the field in different directions.

Thus with a half revolution the direction of flow of current has been reversed or alternated and with another half revolution it will again change, thus returning to the original direction. With every complete revolution there are two alternations or changes in the direction of the current flow.

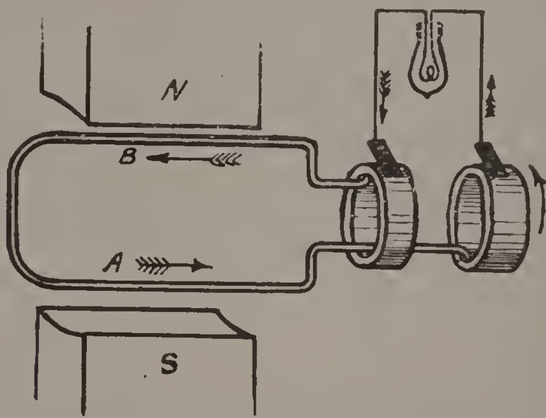


Fig. 73.

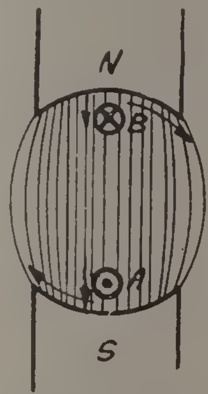


Fig. 74.

This is called an alternating current, and, as we will learn later, it is particularly adapted for long-distance transmission work and some power purposes. However, if used for electroplating, for instance, it would be of no value, as the particles deposited on a plate from the solution while the current flowed in one direction would be immediately cast back into the solution during the next alternation. Thus one alternation would undo the work of the preceding one. A direct or continuously flowing current would be required in cases like this. For lighting and some other purposes also, direct current, as a rule, is superior.

If the simple change is made to the machine described in Figures 69, 71 and 73, of substituting a split copper tube as illustrated in Figures 75, 77 and 79 for the collector rings, a direct current will

be supplied instead of alternating. This spilt tube should be so arranged as to turn with the coil as the rings did in the previous illustrations. As the rotation is taking place in the position illustrated in Figs. 75 and 76, there would be voltages induced in the conductors *A* and *B* tending to make current flow in the directions indicated by the arrows.

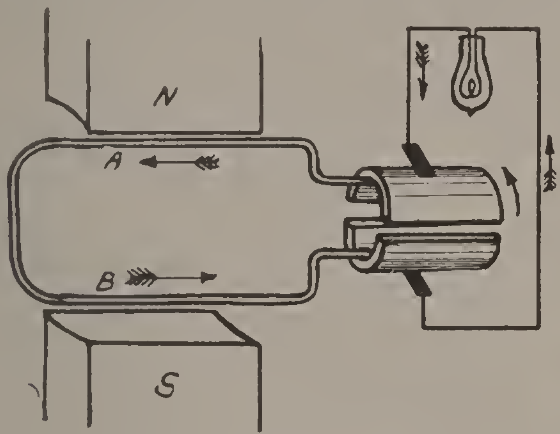


FIG. 75.—SIMPLE DYNAMO.

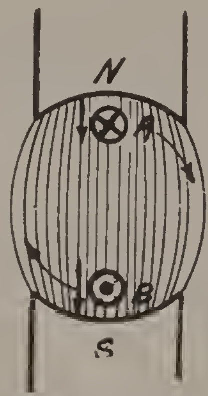


FIG. 76.

In Fig. 77 the coil has turned through one-quarter of a revolution and at this instant the conductors *A* and *B*, instead of cutting through lines of force, are moving along in a direction parallel with

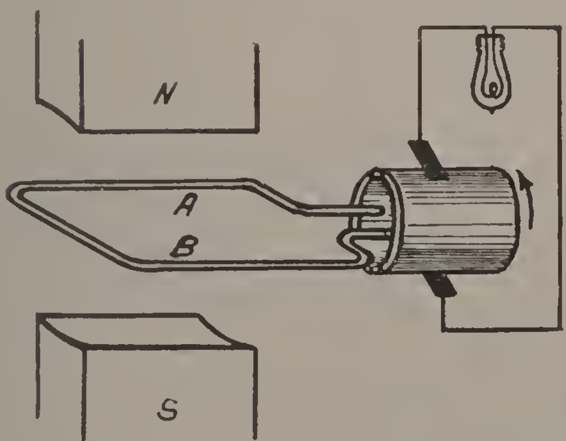


FIG. 77.

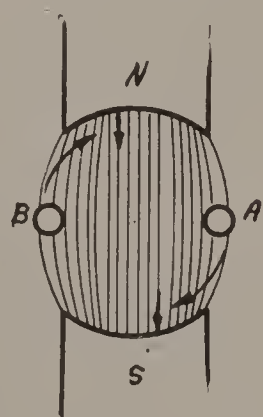


FIG. 78.

them. Consequently, at this moment the number of interlinkages is not changing, no voltage being induced in the conductors *A* and *B*, and neglecting

other influences there will be no current flowing either in the conductors *A* and *B* or in the external circuit. As the coil turns through another quarter revolution to the position shown in Fig. 79, the number of interlinkages will be changing and voltages will be induced in *A* and *B* accordingly, tending to make currents flow in *A* and *B* in the directions indicated by the feathered arrows. On comparing Figures 75 and 79, one peculiarity noticed is, that while the direction of flow of current in the external

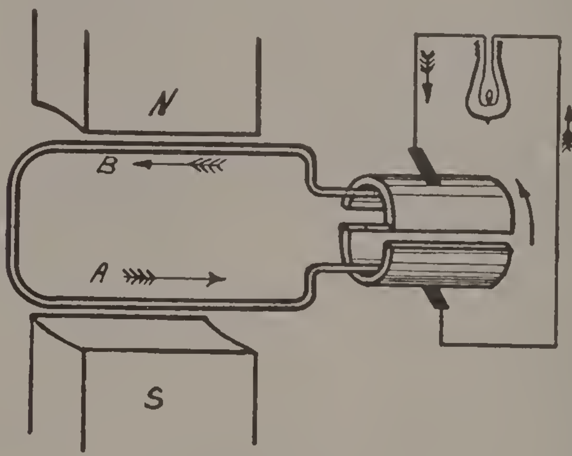


FIG. 79.

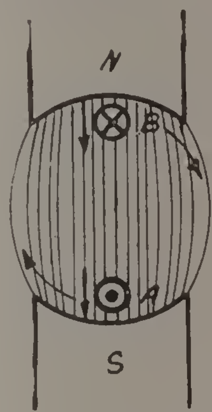


FIG. 80.

circuit remains the same, it has been reversed in conductors *A* and *B*. Thus the current in the external circuit is direct, while in *A* and *B* there is flowing an alternating current. This is due to the split copper tube, and on account of its rectifying or commuting action it is called a **commutator.**

In all commercial machines for generating electricity on these principles, there must be, essentially, two parts: A magnetic circuit or field, and an electric circuit, so arranged as to allow a relative motion which will cause a change in the number of interlinkages of the two.

CHAPTER XI

ARMATURES

Ring and Drum — Construction — Windings.

With the magnet and the rotating coil and commutator, described in Figures 75, 77 and 79 in Chapter X, the voltage obtainable depends, of course, on the rate per second at which the lines of force are cut by the conductors. This rate of cutting depends on and is proportional to the strength of magnetic field, and the speed of rotation. As it is impracticable to have the field with more than a certain number of lines per square inch or centimeter, and also unwise to exceed a certain speed, the amount

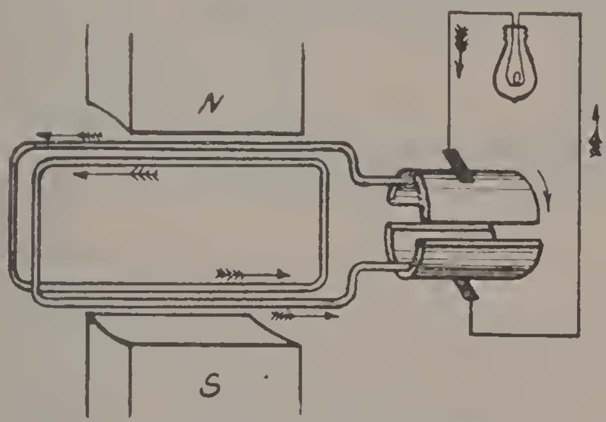


Fig. 81.—Simple Armature with Coil of Two Turns Connected in Series.

of voltage obtainable with this device is limited. If we wish to obtain more voltage, a coil with two turns can be substituted for the one shown in the previous lesson.

Thus with the arrangement shown in Fig. 81. we would obtain twice the voltage if the coil is

rotated at the same speed and the magnetic field has been maintained at a constant value. As the coil turns and cuts through the lines of magnetic force, a certain voltage will be induced in each of the four wires, tending to make current flow in the direction indicated by arrow-heads. These pressures in the four wires or two loops are all in such directions as to help each other and the resultant or sum will be twice as great as when there were only two wires or one complete loop.

This process might be carried still further and a coil wound with three, four, or even more turns, the voltage obtainable being increased in proportion. As the voltage increases, more and more current will flow around the circuit, in time becoming so

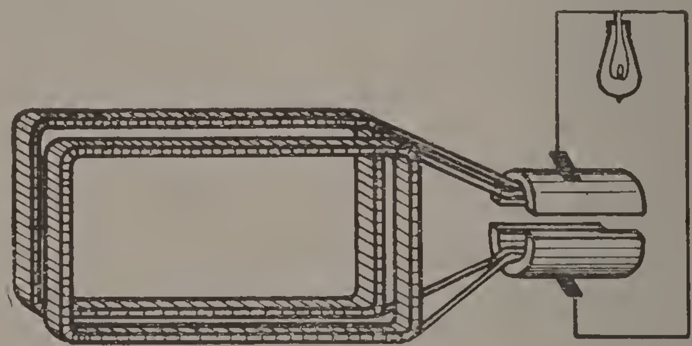


FIG. 82.—TWO COILS CONNECTED IN PARALLEL.

large that the wires in the rotating coil would be overheated. To overcome this excessive heating, it would be necessary to connect a second coil in parallel with the first. Then the two coils, being in multiple and of the same number of turns, would present a double path, and half of the current would flow through each part. The voltage of the second would be the equal to that of the first or original coil and as the two are connected in multiple, the voltage supplied by the machine to the outside line is the same as before.

Actual machines used in practice have comparatively large numbers of coils in the winding of the moving element, each consisting of many turns. These are wound or placed on an iron core, which is mounted on a shaft, together with the commutator. The coils, core, commutator and shaft all revolve together, the complete rotating element being called the **Armature**. By varying the connections of the coils in the **armature winding,** different voltages and current-carrying capacities can be obtained.

FIG. 83.—COILS FOR WESTERN ELECTRIC DRUM ARMATURE, READY FOR PLACING IN SLOTS.

Two general forms of armatures, distinguished from each other by the shape of the core and the position in which the coils are wound or placed, are **Drum** and **Ring**. Drum armatures are more widely used, and one is illustrated in Figures 83, 84, 85, and 86.

It would at first seem that the cheapest and easiest way to make a core would be by casting, but if made in one solid body there are excessive **eddy currents** induced in the iron and in this way there is considerable power lost and the core becomes overheated.

If any electrical-conducting material is moved across lines of magnetic force a voltage is induced in the material. As the coil in Figure 87 revolves, currents will flow in directions shown. This is true

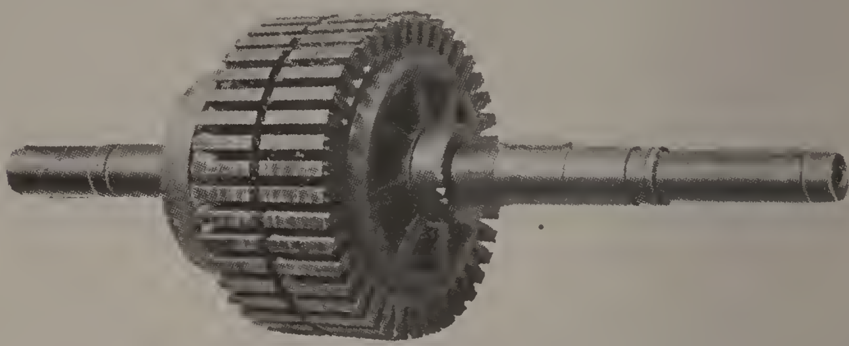


FIG. 84.—WESTERN ELECTRIC DRUM ARMATURE CORE, READY FOR WINDING.

whether the coil be made of copper, iron or any other substance, so long as it is a conductor. In the same manner consider section of an armature core as shown in sketch 88, assuming it to be solid rather

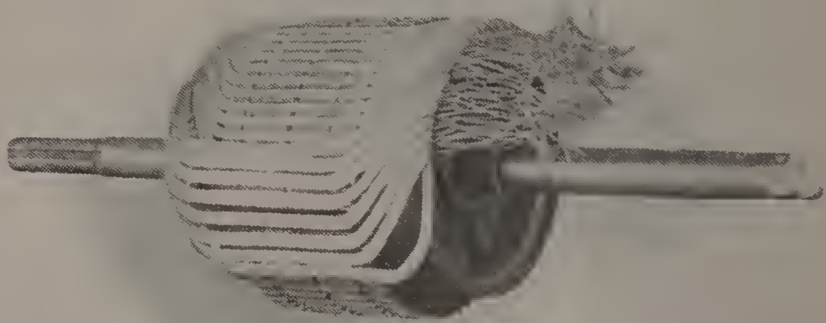


FIG. 85.—GENERAL ELECTRIC DRUM ARMATURE, PARTLY WOUND.

than consisting of punchings. As this section of the core revolves, different voltages will be generated in *A*, *B* and *C*, as *A* cuts all the lines of force, *B* $\frac{2}{3}$ and *C* $\frac{1}{3}$ of them. If, for example, $\frac{1}{10}$ of a volt is

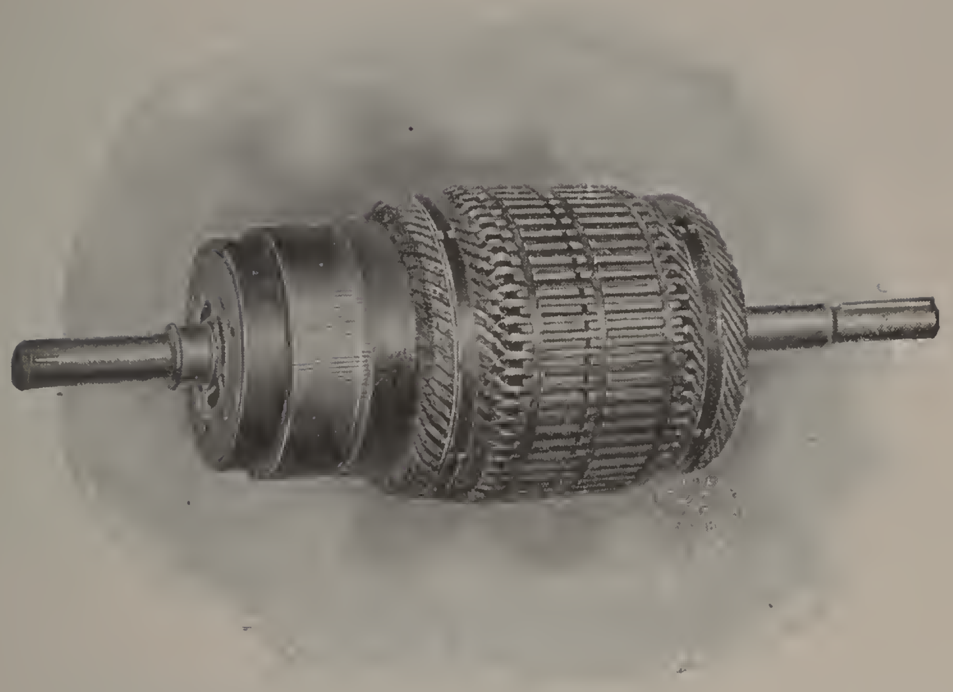


FIG. 86. — GENERAL ELECTRIC COMPLETED DRUM ARMATURE, WITH COMMUTATOR.

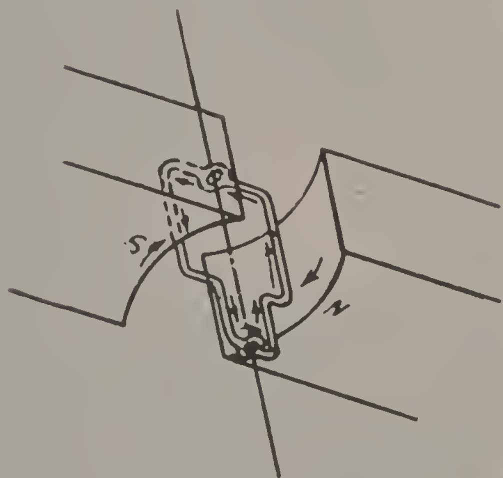


FIG. 87.

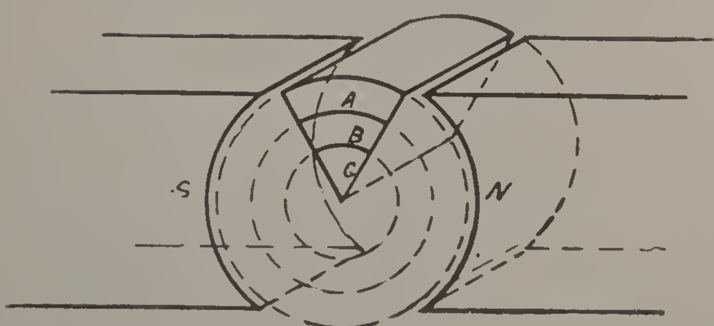


FIG. 88.

generated in C, there will be generated in B $\frac{2}{10}$, and in A $\frac{3}{10}$ volts, illustrated by Fig. 89A.

If voltage in Section A is three times that in Section C, a current will flow in the iron as shown in sketch 89B. These currents cause heating and a

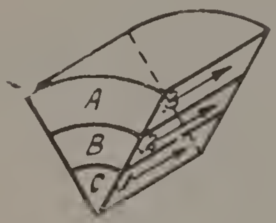


FIG. 89A.

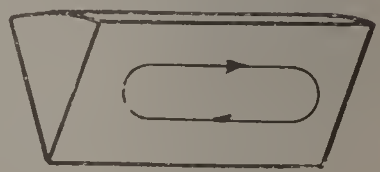


FIG. 89B.

FIG. 90.—PUNCHING FOR ARMATURE CORE.

consequent loss of energy. On account of their circular course these are called **Eddy Currents** and are practically eliminated by making the armature cores of japanned punchings. The japanning

serves as an insulator or obstruction to the flow of eddy currents, except in each individual punching.

Some of these discs, punched out on presses, are shown in Fig. 90. In small armatures they are often mounted directly on the shaft, as shown in Fig. 91. The discs fit against a shoulder on one end and after the proper number has been mounted on the shaft they are tightened in place by the nut shown on the right-hand side. It will be noted that there is a keyway in the shaft and a corresponding slot on the inside of the discs. A key is inserted in these openings and prevents the laminations from turning

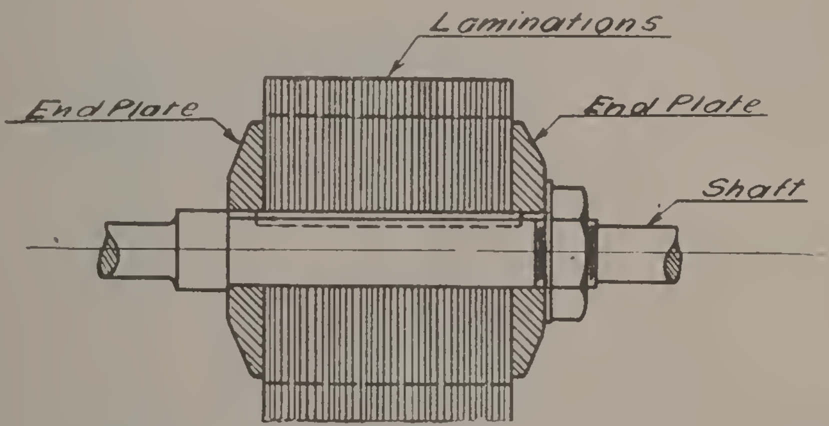


Fig. 91.—Cross-Section Drawing, Showing Construction of Small Armature Core with Punchings Mounted Directly on Shaft.

or slipping on the shaft. The outside of the discs are punched with a number of slots, and when the armature core is complete, these constitute or form receptacles in which the wires or sides of coils are placed.

In early days **smooth-cored armatures** were used and the windings held in place principally by binding wires. The advantages gained on modern armatures by placing the coils in the slots are numerous, foremost of which is the protection of the wires and coil insulation from mechanical injury and the more compact and stronger construction gained thereby. Very often channels of fibre or strips of

other insulating materials are placed in the slots between the coils and the core, preventing the chafing or cutting of the coil insulation by the rough edges of the laminations and the resulting short-circuits and possible grounding of the winding, as well as assuring greater reliability of operation and less danger to operators.

As we increase the number of coils it is advisable to connect the coils to different commutator segments. If a large number of coils were connected to one segment there would be a large current, and this would cause injurious sparking every time the segment passed the brush. This is taken up more fully under Commutation, later on.

Thus, as the armature windings in actual machines consist of many coils, we see also com-

Fig. 92.—A Commutator Bar.

mutators consisting of many segments, and each segment must be thoroughly insulated both from the others and from the shaft or spider on which they are mounted.

Besides being well insulated from each other, the segments must be held firmly in place, for if this is not done, one or more of them may become loose as the armature is rotated and thus give what is known as a "high bar." the loose part or segment projecting above the others and with each revolution raising the brushes and throwing them away from the commutator surface, thus causing sparking and chattering of the brushes. Commutator construction involves careful mechanical work and is a very important part of the machine.

Figure 92 shows a commutator segment, which is pressed or punched out from thick bar-

copper. Mica is the most generally used substance for insulation in commutator work, and the most satisfactory form is that known as split mica, which is simply ordinary sheet mica split up into small pieces which are tested up for imperfections, breaks and metallic veins, substances which would injure the insulating quality. These small pieces are pasted together with shellac or an insulating compound or varnish and in this manner a sheet of large dimensions can be made up with much higher insulating qualities than that of mica found in its natural state.

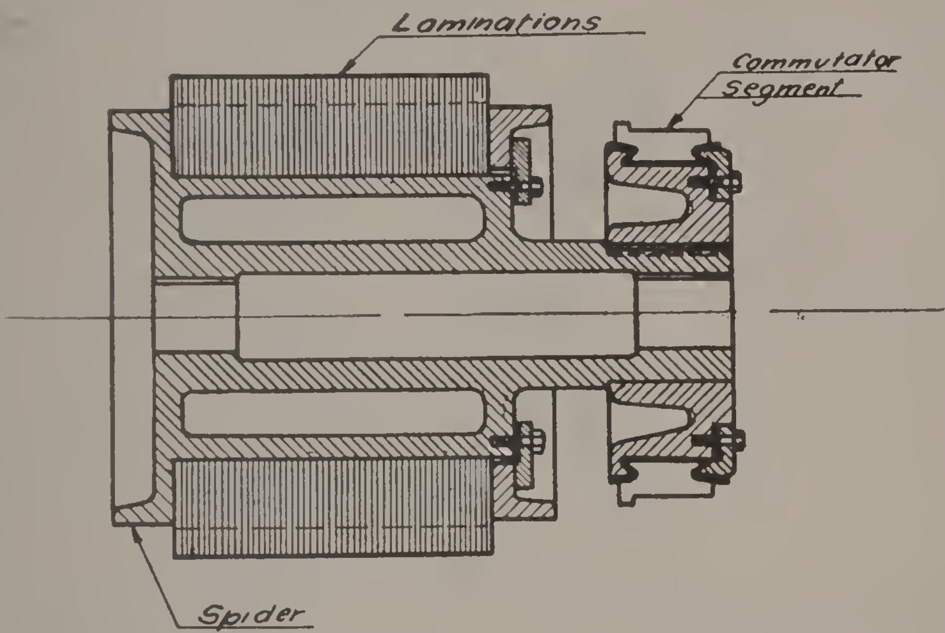


Fig. 93.—Cross Section of an Armature and Commutator Without Winding. Core Mounted on Spider.

To build a commutator, the proper number of segments are assembled in ring shape, sheets of mica being used to separate the segments from each other. Then V-shaped rings of mica are pressed in the two grooves shown, and on top of these are fitted the lips of the end plates. As the two end plates are tightened or pulled together by screwing the nuts on the bolts, it causes the segments to be firmly held in place. It will be noted that in the radial

lug, on each commutator segment, is a small groove or slot, into which the ends of the wires or conductors from the armature coils are soldered.

In the larger machines there are a great many coils in the armature windings and a corresponding number of slots in the armature cores. To one unfamiliar with the method of connecting the coils it may at first seem a very complicated process. However, all armature windings depend on the same principles and methods of connection, and if a few of the more simple forms of windings are mastered

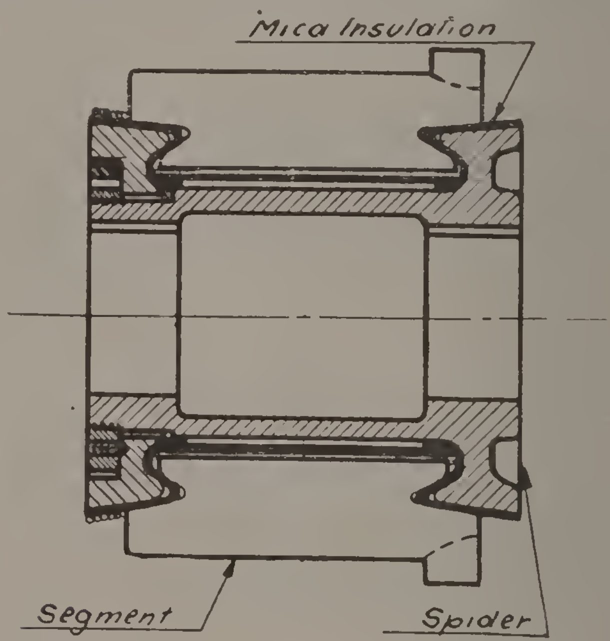


FIG. 94.—CONSTRUCTION OF COMMUTATOR.

and the principles understood, the more intricate ones can be readily grasped. Windings on drum armatures can be divided into two general classes: **Multiple** or **Lap** windings, and **Series** or **Wave** windings. These two kinds of winding can be easily distinguished.

But before going into the winding as a whole, there are two or three things about the individual coil that it will be well to consider. Fig. 95 shows one coil of a drum armature winding in a multipolar field. The two slots X and Y contain the sides of

the coil and are separated from each other on the periphery of the armature by an angle α which is called the **angular pitch** or **spread of the coil** and should theoretically equal a **pole pitch,** represented by angle β, which is the angle between the pole centers. On a bipolar machine the pole pitch would be 180°, on a four-pole machine 90° and on a six-pole machine 60°, etc. In ordinary machines the angular pitch of the coils is just a little less than the pole pitch of the machine, as this shortens the end

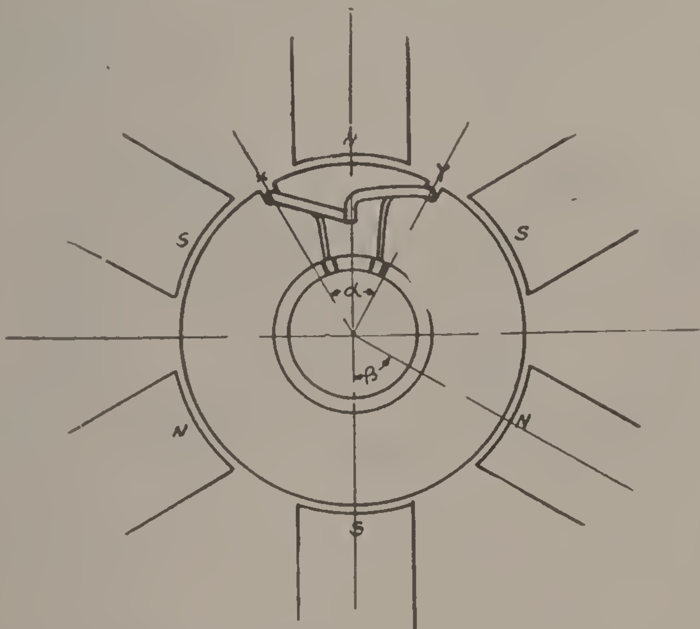


FIG. 95.—SKETCH SHOWING SPREAD OR PITCH OF AN ARMATURE COIL.

connections of the coils from slot to slot and saves copper. If the angular pitch of the coil is made too small, however, it will cause trouble in commutation and will not work efficiently. This will be seen more clearly in a later chapter, where commutation is taken up.

The connection pitch of a winding may be defined as the number of commutator segments which are overlapped by the ends of a coil, or in other words, if all the commutator segments were numbered consecutively 1, 2, 3, etc., and the connection

pitch, say for instance, is 8, it would mean that the two leads from one coil would be connected to segments 1 and 9.

Fig. 96 represents the difference in coils such as would be used in multiple or lap windings and in series or wave windings respectively. It will be noted in the multiple or lap windings in Fig. 97, the ends of the coils come back to adjacent segments of the commutator and the coils of such a winding lap over each other. In the series windings the coil ends instead of coming toward each other diverge and go to segments widely separated on the commutator, and, as will be seen in Fig. 97, the winding

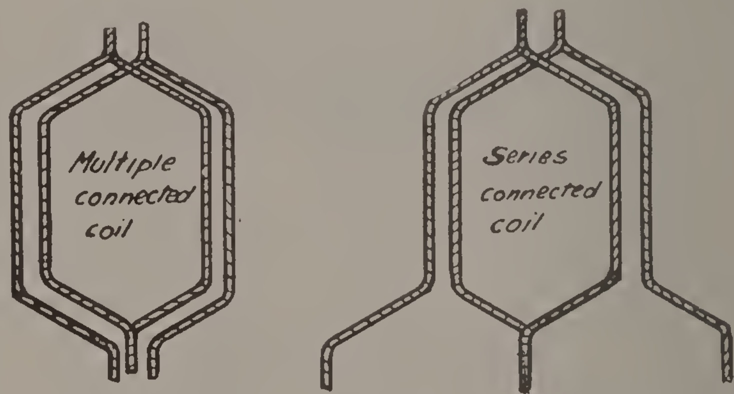


Fig. 96.—Armature Coils for Lap and Wave Windings.

to a certain extent resembles a wave and the coils are all in series by the method of connection.

Fig. 98 represents a bipolar winding with 16 slots, 8 coils and 8 commutator segments. At first it may seem that the wires are criss-crossed back and forth in a haphazard manner. But with a clockwise rotation of the armature, as indicated by the arrow, let us see the direction currents will tend to flow in the different armature conductors, if leads were connected from the brushes *B*, *B*, to an external circuit. It will be seen that there are four conductors under each pole: 3, 4, 5, and 6 under the south pole, and 11, 12, 13 and 14 under the north pole. Each one of these coils in an actual winding

might consist of many turns, although here only one turn is used for simplicity, and in tracing out the connections the solid lines represent the connections on the front of the armature from the commutator bars to the slots, while the dotted represent the connections on the back of the armature, or in other words, merely the rear end of the coils.

By the rules given in previous pages, currents would tend to flow in 3, 4, 5, and 6, in a direction

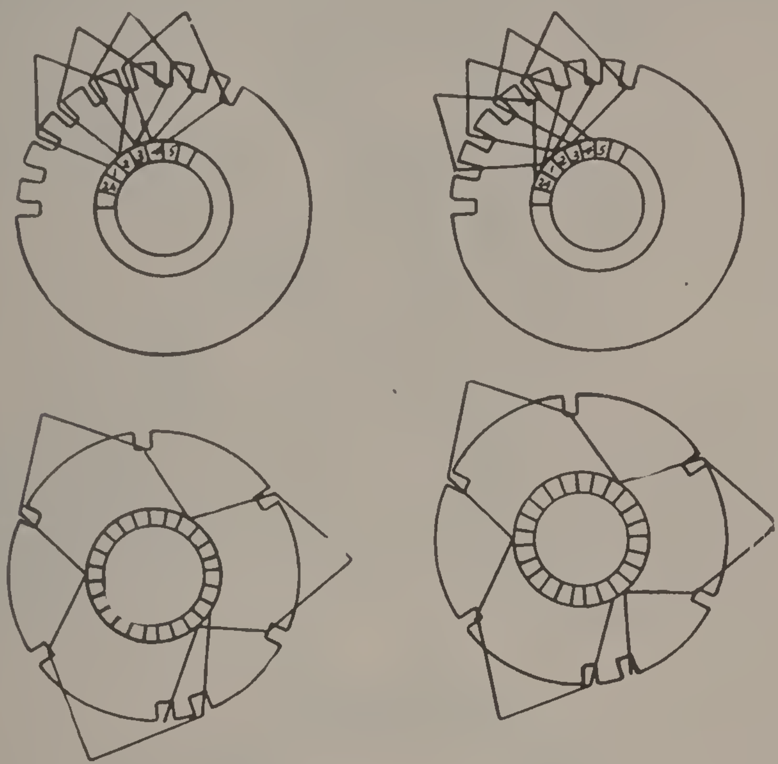


Fig. 97.—Winding Diagrams for Lap and Wave Windings, with Forward and Backward Progression.

toward the observer up through the paper, and in 11, 12, 13 and 14 in a direction away from the observer. If we trace the relative connection between the coils and commutator, we will see that these induced voltages in the individual conductors on each side of the armature are all added together and help one another, so that the total voltage or pressure between the two brushes is the sum of all on that side.

Suppose the brushes B, B, are connected to an outside circuit and the generator is in operation. Let us trace out the direction of flow of current through the winding. Brush B_1 at the instant

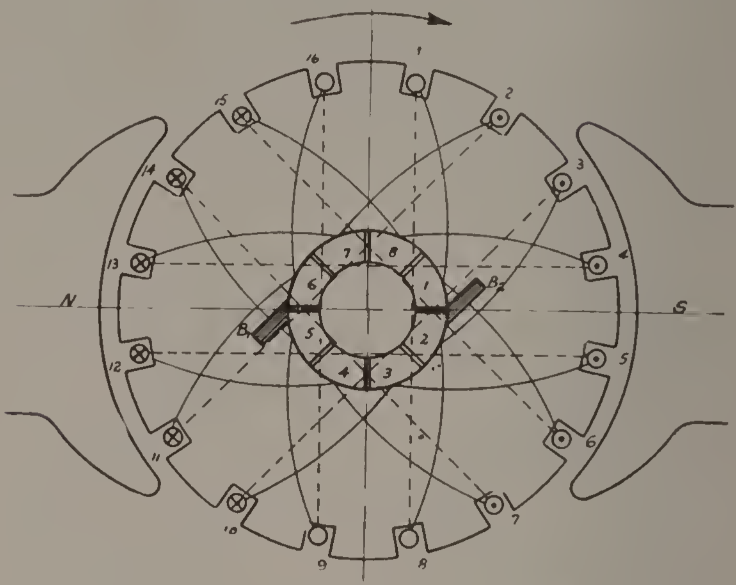


FIG. 98.—SIMPLE BIPOLAR DRUM WINDING.

shown is touching commutator segments 5 and 6, and the current would be entering the machine from the outside circuit at this point. On leaving the brush it would divide, part going to commutator

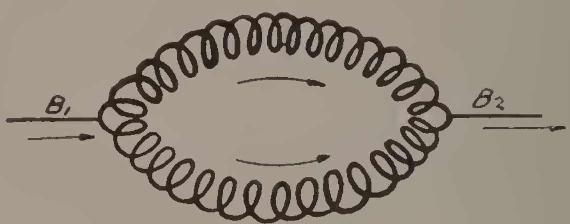


FIG. 99.—ELECTRICAL CIRCUITS IN BIPOLAR ARMATURE WINDING.

segment 5 and part going to commutator segment 6. In other words, there will be two paths offered to the flow of current. We will take them up separately:

After the current leaves commutator segment 6, there are two wires from 6 which would conduct

current, one leading to conductor 16, the other leading to conductor 11. But if current was conducted to slot 16, down the slot and across the back of the armature, as indicated by dotted line, to conductor 9, up the slot and across to commutator segment 5, as shown by solid line, it would merely be back to the brush again. In other words, the coil whose two sides are conductors 9 and 16 is short-circuited by the brush, and on that account we will consider that no current is flowing in this coil.

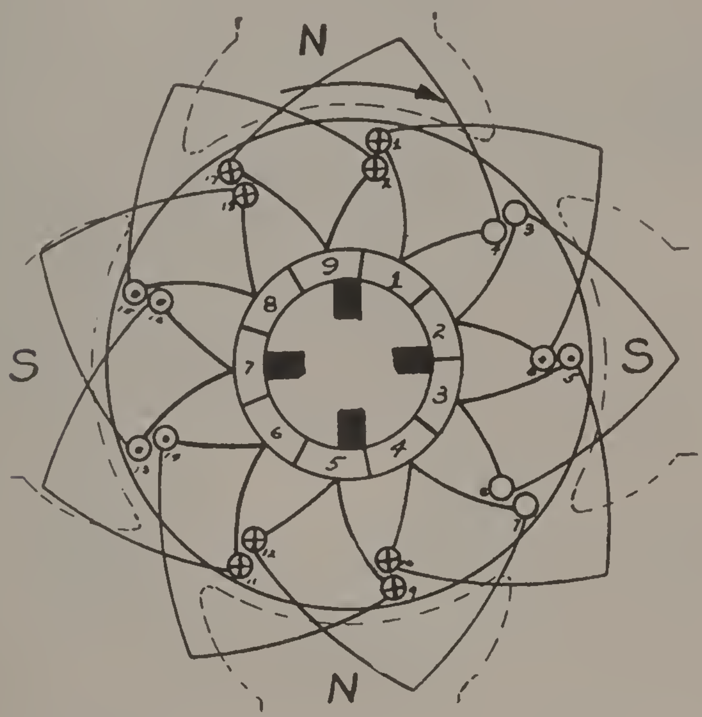


FIG. 100.—FOUR-POLE LAP WINDING.

Again going back to segment 6, the current could take the other lead to conductor 11, by the dotted line to conductor 2, come up the armature to the front and down as indicated by the solid line, to commutator-segment 7, and from there into conductor 13, down the armature, across the back from 13 to 4, from conductor 4 to segment 8, from there to conductor 15, from conductor 15 to conductor 6, from conductor 6 to segment 1, from there to the outside

circuit via the positive brush B_2; after leaving the machine the current goes on the outside circuit around through the lamps or other load we may have, after which it returns to the machine, entering as before by brush B_1, which is called the negative brush on a dynamo.

On entering the machine through the brush B_1, let us consider the other path offered to the current, or in other words, start with segment 5, from there to conductor 14, down by the dotted line

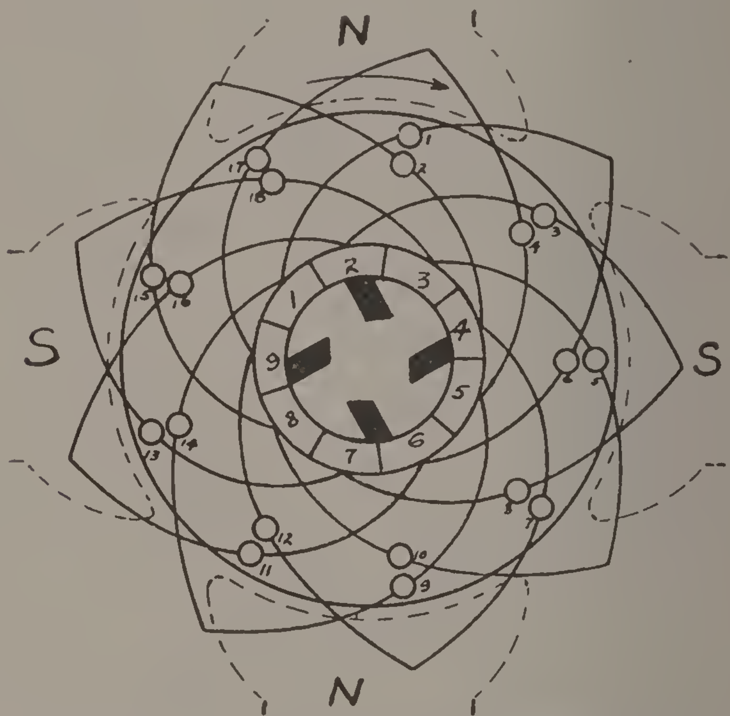


FIG. 101.—FOUR-POLE WAVE WINDING.

to conductor 7, from conductor 7 to segment 4, to conductor 12, to conductor 5, to segment 3, to conductor 10, to conductor 3, to segment 2, to positive brush and out to the line again.

Tracing the direction of the current as it flows through the winding shows that between the two brushes there are two paths in multiple. The winding might thus be said to have two circuits, and sometimes an armature winding of this type is repre-

sented in sketches by a complete circular ring of winding with two taps at diametrically opposite points, the current entering at one and leaving at the other.

In drum windings every conductor on the armature is active, cutting lines of force during each

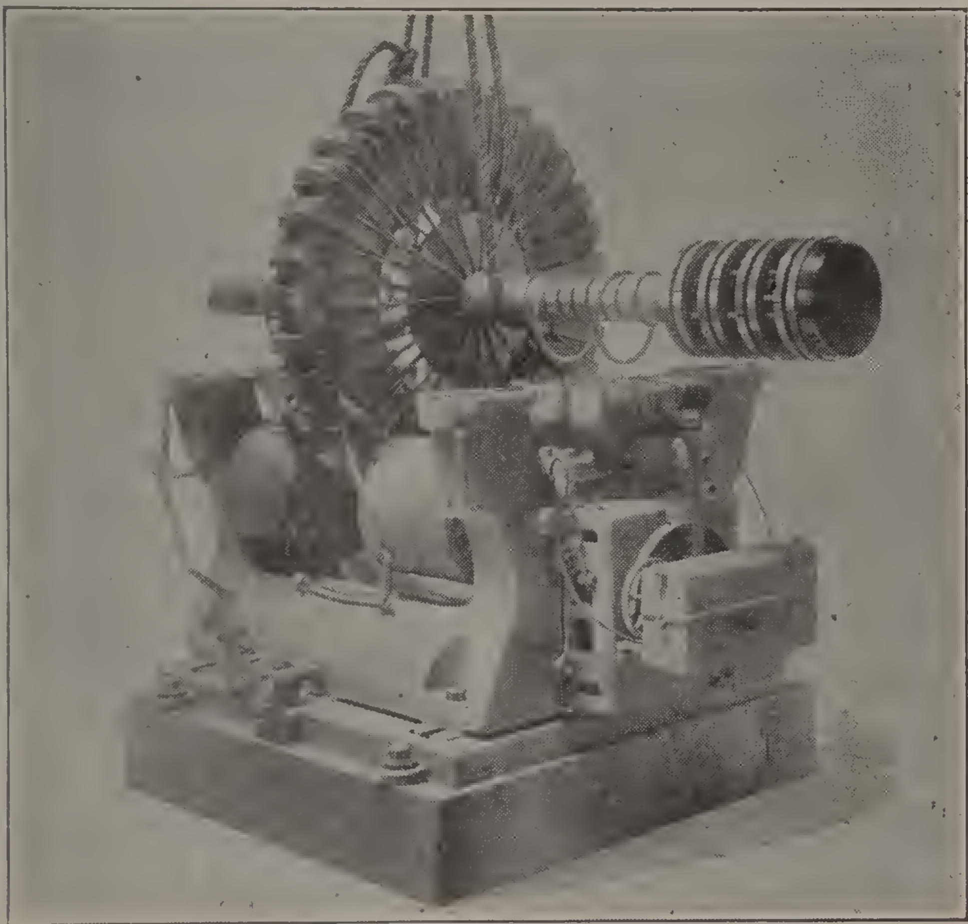


FIG. 102.—RING-WOUND ARMATURE, AS USED ON BRUSH ARC-LIGHT GENERATORS.

revolution, the only parts of the coil doing no useful work being the back connections and the leads from the slots to the commutator segments.

In ring armatures the core is ring-shaped and supported on a spider, which is in turn mounted on the shaft. The windings are wound around the ring. A ring armature is shown in Fig. 102 and

diagrammatically in Fig. 103. The distribution of lines of force in a bipolar machine with ring armature is shown in Fig. 104, and, as will be seen in the rotation of this armature, the conductors on the inside surface of the core will cut or interlink with

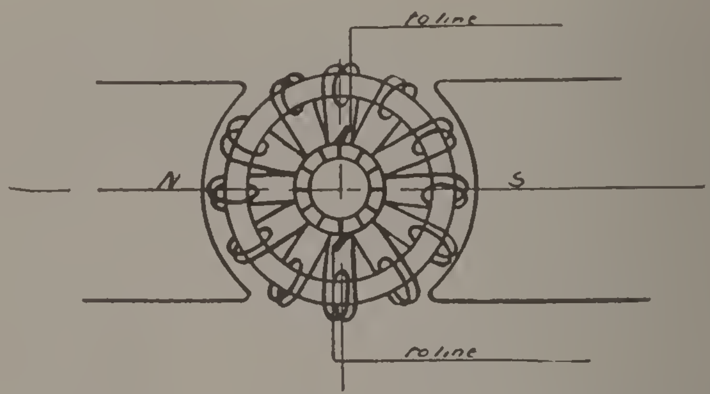


FIG. 103.—DIAGRAM OF RING WINDING.

practically no lines of force and consequently will do no useful work. Therefore, in a ring winding, in addition to the end connections on both back and front of the armature, we have the inside part of the coil inactive; and the resulting uneconomical use of

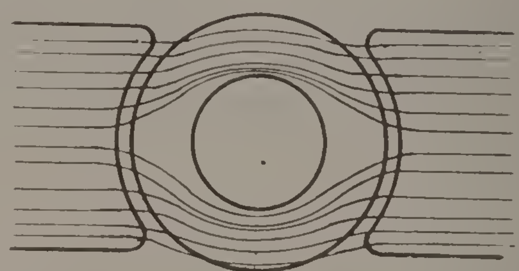


FIG. 104.—PATH OF MAGNETIC FLUX IN RING ARMATURE.

copper, and the difficulty of winding such a shaped core, are factors in preventing a low cost of production for ring-armature machines, and in limiting the field of their application. On the other hand, by their shape and the method of winding such armatures,

the coils do not overlap or touch each other, making it much easier and cheaper to insulate the windings very effectively. For this reason this type of machine is used where a very high voltage is required, such as for series arc-light circuits.

In alternators, a very common method is to place the armature winding around in slots in punchings held by the frame. In these cases the armature is stationary and the field poles revolve inside. This construction is explained in the next chapter.

CHAPTER XII

FIELDS AND FIELD FRAMES

Reasons for Use of Electro Magnets in Preference to Permanent Magnets — Field Windings.

On account of their simplicity and cheapness "permanent" magnets are employed in many electrical measuring instruments and in magnetos, such as are used in motor boats and automobiles. However, it is difficult to make a magnet, the strength of which will not decrease in use, and in endeavoring to turn out magnets that will retain constant strength for several years, makers employ special steel alloys which are put through various hardening and artificial ageing processes. In small sizes the magnets so produced will withstand a remarkable amount of hard usage, their magnetism remaining practically unchanged during long periods of service. However, in anything but very small sizes, it is commercially impossible to produce a satisfactory permanent magnet, and on this account it is universal practice to employ electro-magnets in practically all of the motors or dynamos used in every-day work.

With the development of the electrical manufacturing industry, we find different makers employing a large variety of shapes of field magnets and frames in the construction of dynamos and motors. A very common form in the earlier days of the industry is shown in Figs. 105 and 106, the magnet system being an inverted horse shoe, or U-shape.

Another form is shown in Figs. 107 and 108. This machine was manufactured by the Thomson-Houston Electric Company and was used for in-

candescent and arc lighting purposes, the windings and frame being modified somewhat from the incandescent form when used for arc lighting.

Fig. 105.—Field Magnets and Frames on Early Bipolar Dynamos.

The construction and relative position of the field poles and armature in Fig. 105, as can be

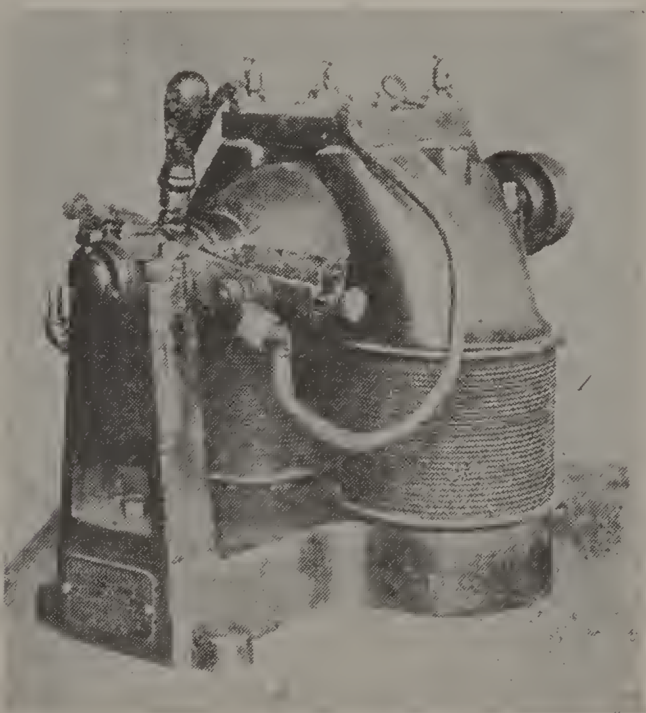


Fig. 106.—Old Style Bipolar Dynamo.

readily appreciated, left the armature unprotected to a large extent and in many cases exposed the windings to injury. To protect the armature, in

the later forms of machines, a circular frame was brought around, enclosing the armature and poles at top, as shown in Fig. 109. The top section of the

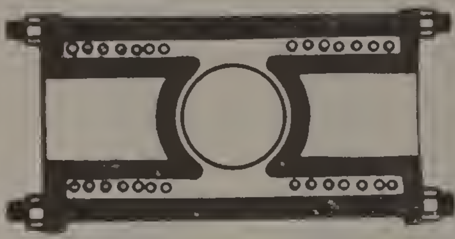


Fig. 107.—Early Form of Field Magnets Used in Thomson-Houston Machines.

frame is made of non-magnetic material, such as brass, in order to eliminate as far as possible any

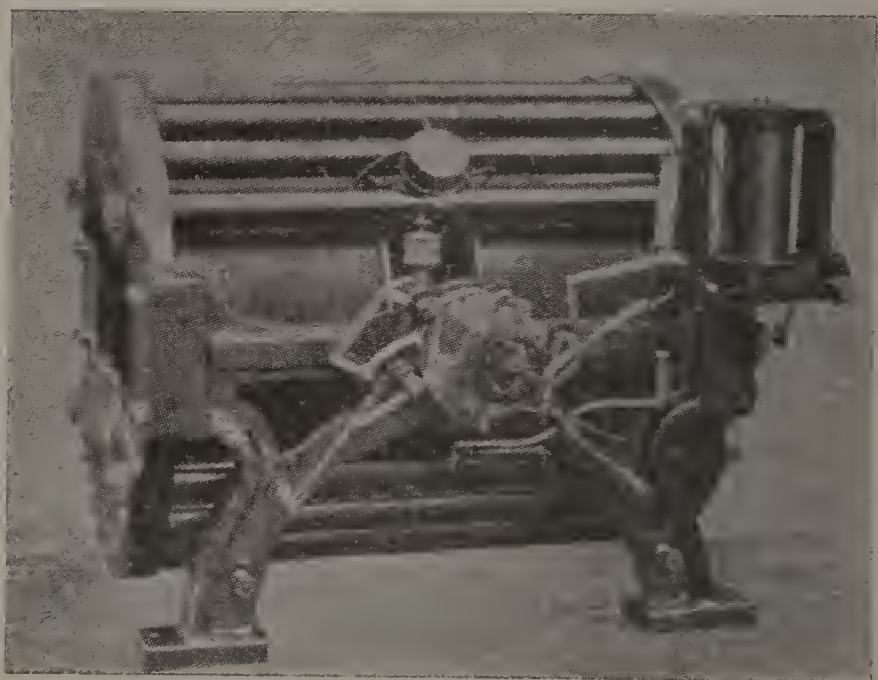


Fig. 108.—Thomson-Houston Arc-Light Generator, Now Obsolete.

magnetic leakage. While this was an improvement upon preceding designs, the outside frame, beyond serving for protection, was inactive and did no

useful work, making the machine heavy for any given size.

In the latest forms of bipolar machines brought out, there is a frame arrangement of field poles,

Fig. 109.—Early Bipolar Dynamo with Frame to Protect Armature.

as shown in Fig. 110. The outside frame, which protects the armature, serves as a part of the magnetic circuit, and for a given size this type of a machine is lighter and more compact than that

Fig. 110.—Modern Bipolar Field and Frame.

shown in Fig. 109. It will be noted in the illustration of this machine, that the end shields, which support the bearings, are shaped to protect the commutator and brush rigging, as much as is consistent with good ventilation. Also these end shields are

fastened to the frame or yoke by means of four bolts 90° apart, permitting them to be rotated either 90° or 180° if desired, in order to prevent the spilling of oil from the bearings when the machine is to be mounted on the wall or suspended from the ceiling.

The machines so far considered have had only two field poles, one north and one south, this being

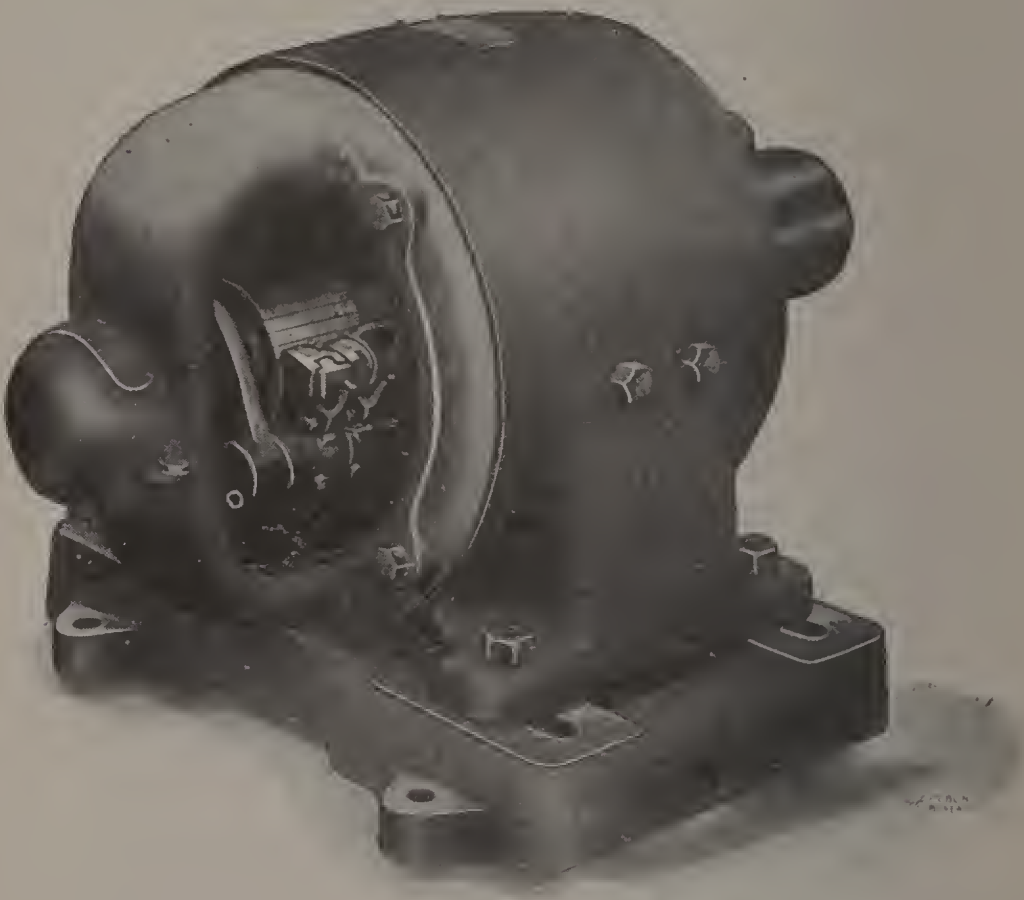


Fig. 111.—General Electric Form CQ Bipolar Dynamo.

the most widely adapted form of construction for generators in the smaller sizes such as 1, 2, 3 and 5 kilowatts. However, in many of the larger sized dynamos, four, six, eight or even more poles are employed, these being called multipolar. There are several reasons for this change in design and construction as the capacity of a machine is in-

creased. Most of the smaller dynamos or motors are of the belted type and are operated at speeds varying from 1,200 to 3,600 R.P.M.

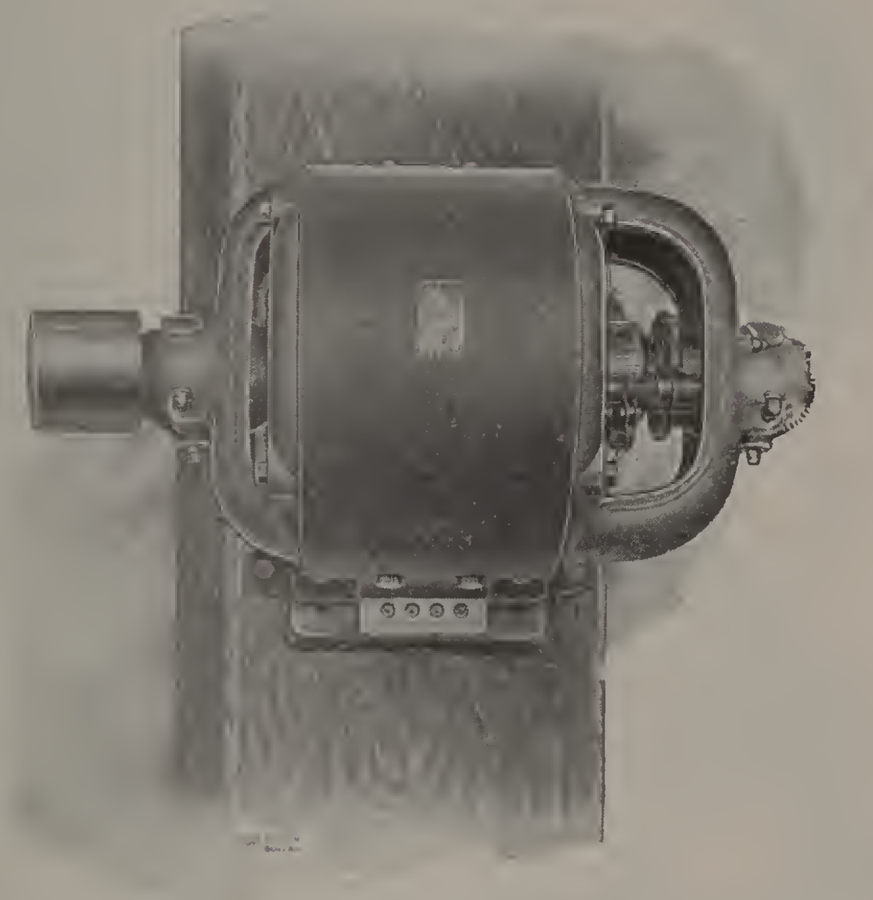


Fig. 112.—CQ Machine Mounted on Post or Wall.

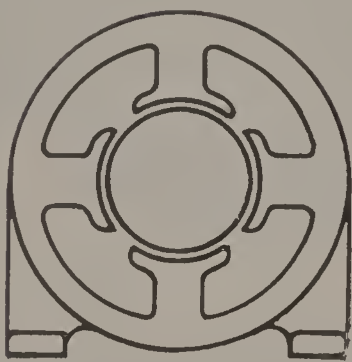


Fig. 113.—Modern Four-Pole Field and Frame.

But in the larger sizes, if the armatures were operated at such speeds, the centrifugal force and

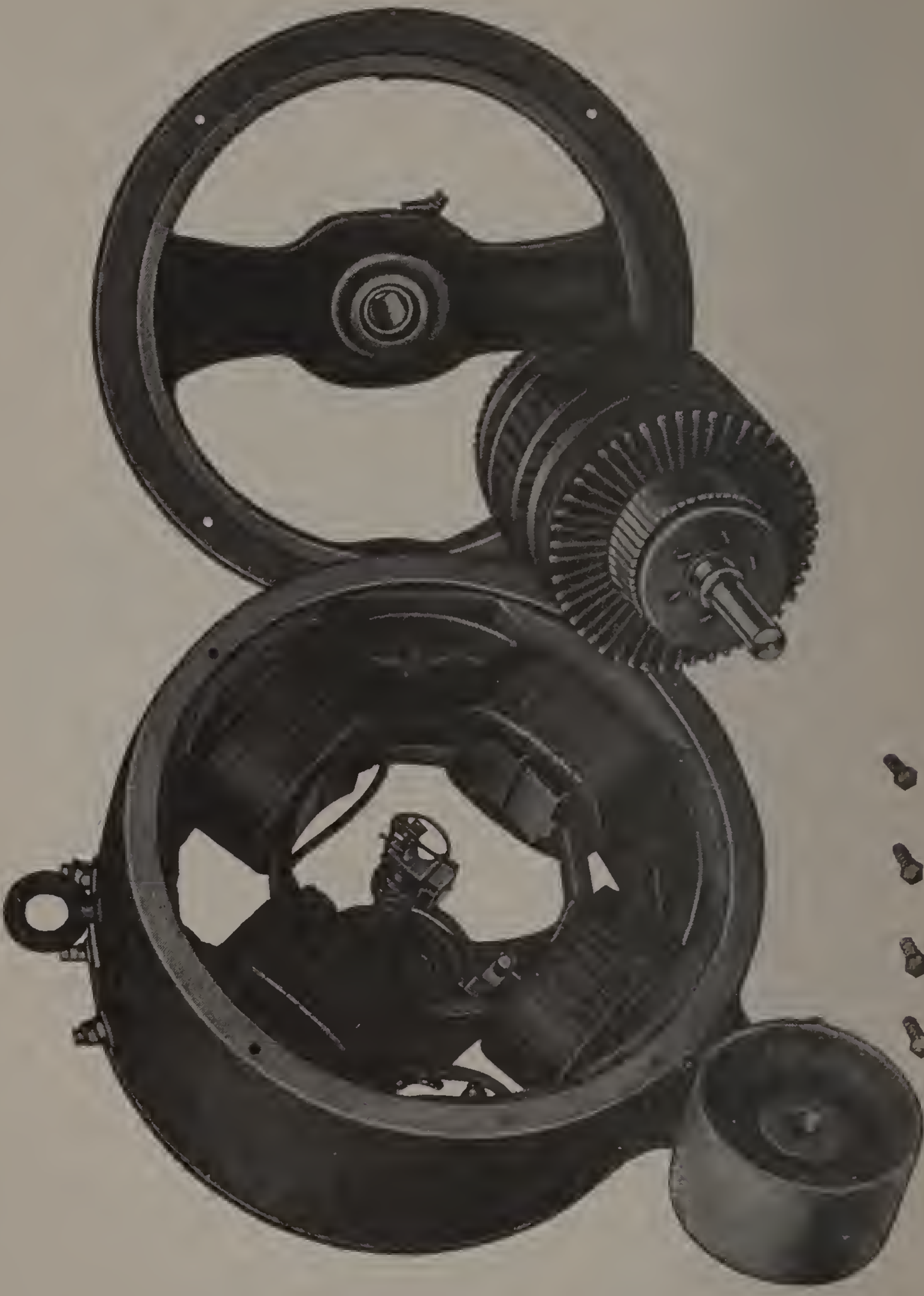


FIG. 114.—FORT WAYNE FOUR-POLE DYNAMO, SHOWING PARTS NOT ASSEMBLED.

consequent mechanical strains would cause them to fly to pieces. Generator shafts are sometimes coupled directly to the main engine or turbine shaft and in such cases the speed of the driven machine is naturally the same as that of the driver. Where

FIG. 115.—FORT WAYNE SIX-POLE GENERATOR.

large Corliss engines are used, this means speeds as low as 80 or 60 R.P.M. Thus the engine equipment is sometimes another factor necessitating low speeds.

As the speed of a generator is lowered, the armature conductors will cut fewer lines of force per second and the voltage decreases proportionally. To maintain the desired voltage the number of armature conductors might be increased, or the poles made larger and the strength of the field increased. This soon leads to very clumsy construction, however, and bipolar machines in larger sizes are seldom built.

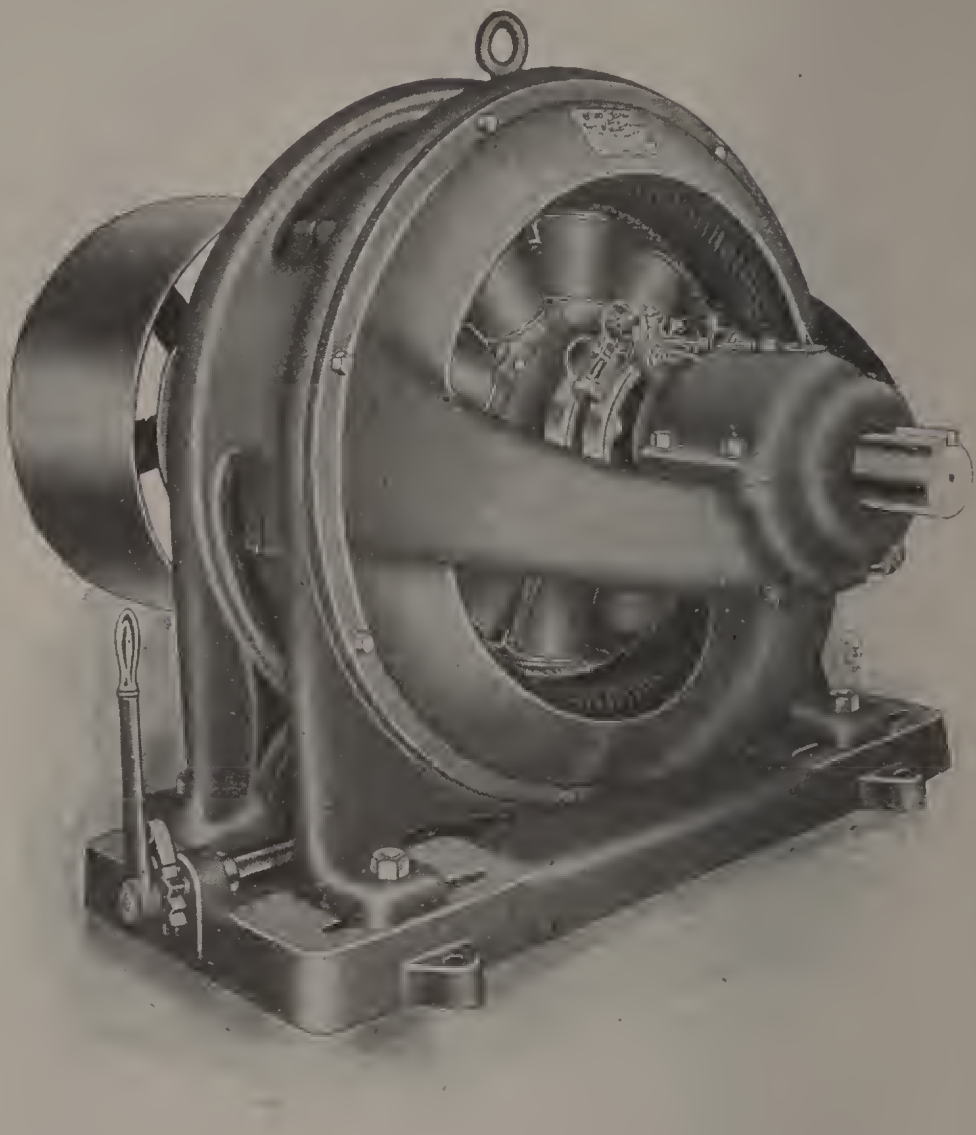


FIG. 116.—FORT WAYNE MULTIPOLAR REVOLVING FIELD GENERATOR.

All of the machines so far considered, whether bipolar or multipolar, consist essentially of a cylindrical armature rotating in a magnetic field, but it is immaterial, theoretically, whether it be the armature or field magnets that are moved. The necessary condition is that there be a relative motion causing a change in the number of **interlinkages.** Fig. 116 represents the external appearance of a machine in which the field magnets revolve while the armature winding is placed around the inside of the yoke and

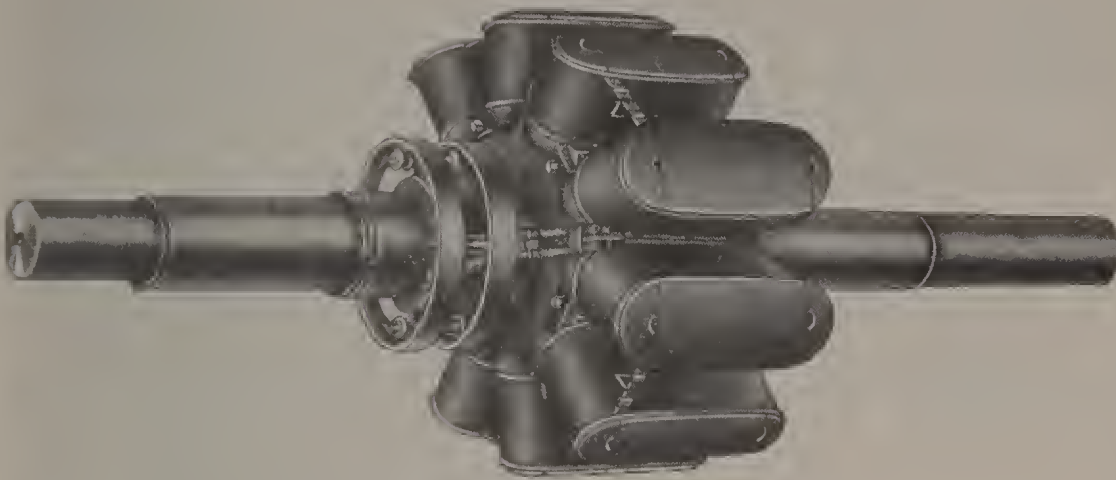


Fig. 117.—Field Structure for Fort Wayne Revolving Field Generator.

Fig. 118.—Frame and Armature for Fort Wayne Revolving Field Generator.

is stationary. Fig. 117 is a view of the rotating element and shows the two slip rings which the brushes press against, and by means of which the current passes through the field windings. Fig. 118 shows the armature winding.

In practically all direct-current machines the field magnets are stationary and surrounding the armature which rotates. With very few exceptions, alternators are now made with revolving field construction.

CHAPTER XIII

METHODS OF EXCITATION

Self, and Separate — Shunt, Series and Compound — Field Windings: Direction of Windings for Proper Polarity — Ampere Turns — Laws Relating to Magnetic Strength.

While permanent magnets are well suited for some purposes the generators used in ordinary commercial work employ electro-magnets, and the current used to energize the windings of these electromagnets is secured either from some external source

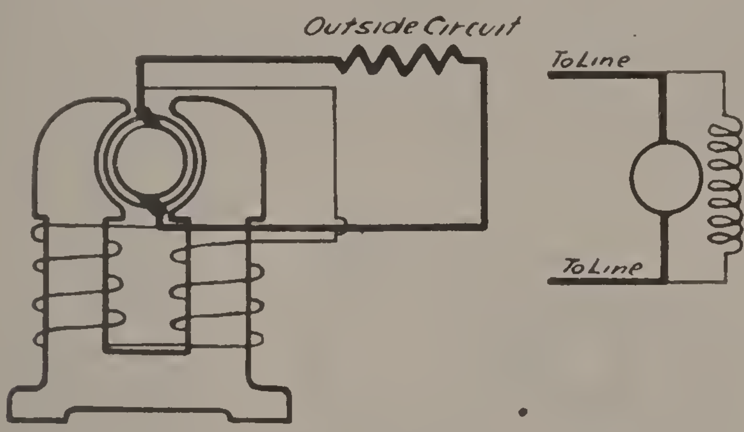


FIG. 119.—ELECTRICAL CIRCUITS—SHUNT MACHINE.

or from the machine itself. The first of these two methods is known as separately exciting the machine, the current being obtained from a separate generator which is called an **Exciter,** as the current it supplies is exciting the field magnets of the first machine. The second method is designated **self excited,** as the machine furnishes its own excitation.

As a rule, alternators are separately excited. Direct-current machines may be either separately or self excited equally well. Figs. 119, 120 and 121

illustrate three methods of connections, known as Shunt, Series and Compound, for self-excited direct-current machines. As will be taken up more fully later on, each of these three types is particularly

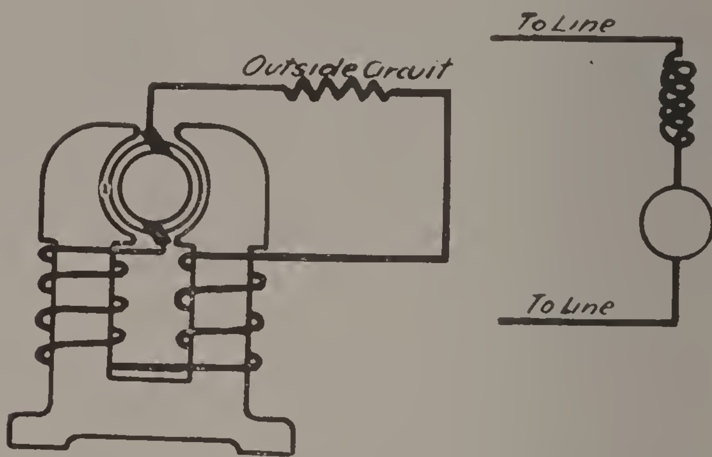


FIG. 120.—ELECTRICAL CIRCUITS—SERIES MACHINE.

adapted for certain applications and should be used for these classes of service in preference to the other two types. We will learn later why this is so and what these applications are.

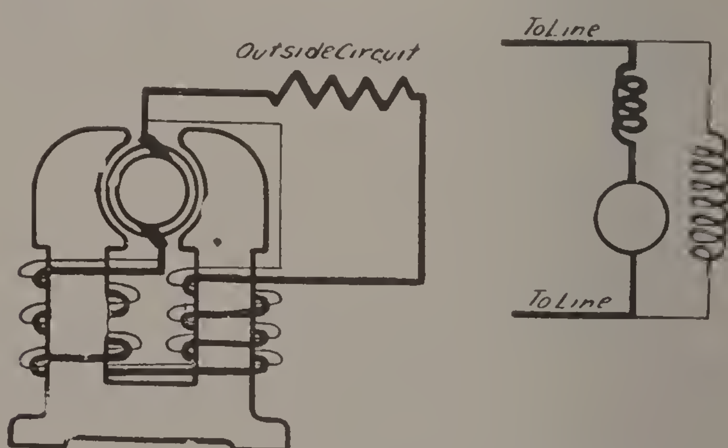


FIG. 121.—ELECTRICAL CIRCUITS—COMPOUND MACHINE.

While there are Homopolar machines on the market they are not being used very extensively up to the present time. In ordinary cases such as we have been considering, the machine must have one north to correspond with each south pole for correct

operation. Thus in a bipolar machine there must be one north and one south pole and in a four-pole machine there must be two north and two south poles, and so on. If either of the windings on the two field poles in Figs. 122 or 123 should be reversed,

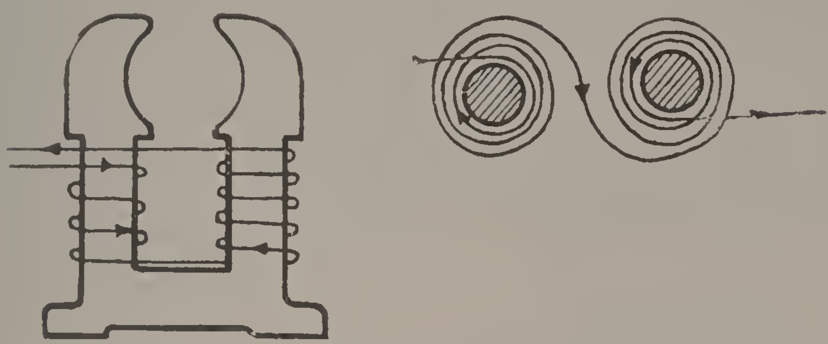


Fig. 122.—Direction of Field Windings on Old-Style Bipolar Dynamos.

changing the polarity, and producing two north or two south poles as the case might be, the machine would be rendered inoperative. The direction in which the windings are placed on field poles is very

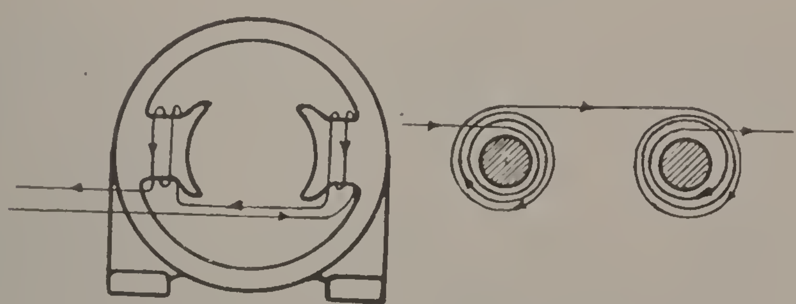


Fig. 123.—Direction of Field Windings, Modern Bipolar Dynamos.

important, and Figs. 122, 123 and 124 will make this point plainer.

Some of the large manufacturers of electrical machinery wind the field coils on forms into a spool-like shape, and after this is completed the winding is covered with tape or fibre and cord wrapping, for the purpose of insulating and protecting it. After

being dipped in asphaltum or some insulating varnish and allowed to dry, the coils are ready to be slipped on to the pole pieces, and in some machines, such as shown in Fig. 114, they are held in place by the pole tip or shoe.

As we have seen, the magnetizing power of a coil is dependent on and proportional to the ampere-turns, which are the product of the turns in the coil by the current flowing in amperes. Thus with two amperes flowing in a coil of 100 turns there are 200 ampere turns, which are sometimes known as the Magnetomotive-Force as they occupy the same

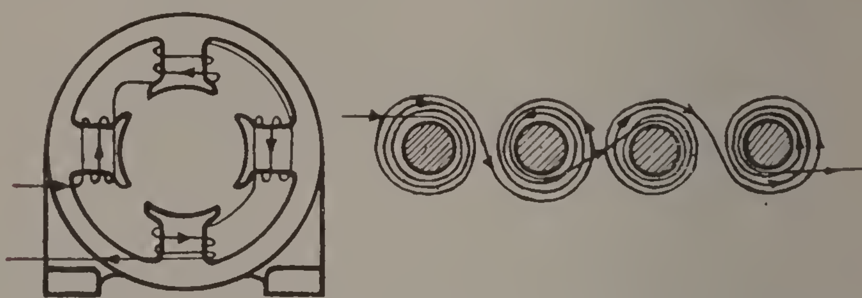


FIG. 124.—DIRECTION OF FIELD WINDINGS, MULTIPOLAR DYNAMOS.

relative position in Electro-Magnetism as Electromotive-Force or voltage does with electric currents.

We speak of the resistance of an electric circuit as that property or force tending to impede or stop the passage of current and which must be overcome as current is made to flow; likewise, as we produce magnetic lines and cause them to circulate or flow, the magnetic circuit has a similar property called **Reluctance**, depending on:

1. **The Cross Section**. Naturally the larger the circuit the easier it will be for the lines to pass, or *vice versa* as the cross-sectional area of the circuit is made smaller, it will be correspondingly harder for the lines to circulate.

2. **The Length.** As a circuit is lengthened more Magnetomotive-Force is required to maintain

a certain number of lines, or as it is shortened the reluctance is decreased.

3. **The Material.** Iron conducts lines very much easier than air. Also steel, and to a lesser extent nickel and other metals, have higher magnetic conductivities than air. This property of substances for conveying lines of force is known as their **permeability,** or as it might well be expressed, their willingness to be permeated by magnetism. As a base, air is said to have a permeability of one. The permeability of iron and steel of course varies with the different grades, in some cases being even as much as two or three thousand times as great as air, which means that lines of force passing through air meet with that much more resistance to their passage. The formula for the reluctance of any magnetic circuit is as follows:

$$\text{Rel.} = \frac{l}{AP}$$

where

A = Cross-sectional area of the circuit in sq. in.
P = Permeability of material.
l = Length of circuit in inches.
Rel. = Reluctance.

The magnetizing power of a coil is proportional to the **ampere-turns** — the product of the turns in the coil by the amperes flowing. The actual number of lines produced in any magnetic circuit equals the magnetomotive force divided by the reluctance; just as in Ohm's Law, for electric circuits, the current in amperes is equal to the volts divided by the resistance in ohms. The formula for calculating the number of lines of force produced by any coil is:

$$\text{Number of lines} = \frac{\text{Magnetomotive Force}}{\text{Reluctance}}$$

$$\varphi = \frac{3.192 \times N \times I}{\frac{l}{AP}} = \frac{3.192 N I A P}{l}$$

where

φ = Number of lines.
N = Number of turns in the coil.
I = Number of amperes flowing in the coil.
A = Cross-sectional area of the magnetic circuit.
P = Permeability of the material.
l = Average length of magnetic circuit in inches.

In any dynamo, if we know the material and dimensions of the magnetic circuit, and also the turns and the current in the field winding, we can calculate the actual number of lines of force in the field. It is very important that the material used and the shape of the armature core, pole pieces and frame be given careful consideration in any machine. These should be so designed as to provide a path of low reluctance for the lines of force. This is the reason why iron and steel are so widely used. While the air gaps between armature and fields in ordinary machines are but a fraction of an inch it requires much more energy to drive the lines of force across this small air space than around all of the remaining part of the magnetic circuit in the iron yoke, pole pieces and core. Joints in the magnetic circuit when two pieces of iron come together will increase the reluctance very appreciably unless made very carefully.

If the armature conductors in any machine are cutting only half of the lines emanating from the pole pieces, it is evident that the voltage generated and the efficiency of the machine are only half as great as they would be, were all the lines being cut. In other words, it should be our aim to have as far as practicable, every line pass through the armature.

This question of **magnetic leakage** is quite an important one. It will be seen on reference to the illustrations that the leakage is less in Figs. 125, 127

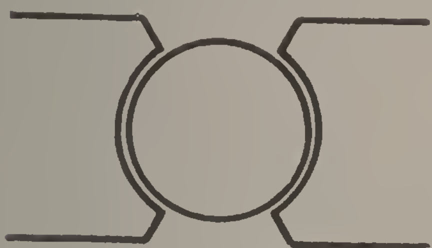


FIG. 125.

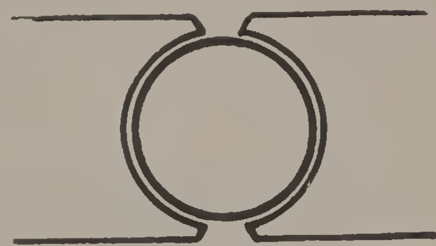


FIG. 126.

FIG. 127.

FIG. 128.

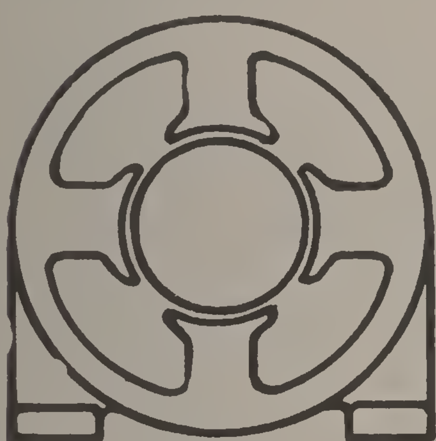


FIG. 129.

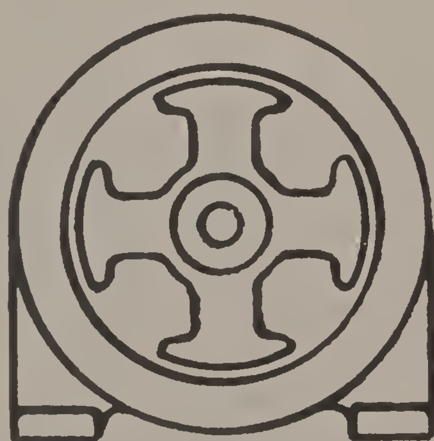


FIG. 130.

FORMS OF POLE TIPS.

and 129 than in Figs. 126, 128 and 130, the shape of the pole tips or shoes having a great deal to do with this factor in determining the efficiency of a machine.

CHAPTER XIV

VOLTAGE

Formulas — Rheostats — Effect of Resistance in Series with the Field Windings on the Voltage Being Maintained or Generated by a Dynamo — Effect of Resistance in Series with Armature.

With each revolution of the armature, shown in Fig. 131, every conductor will cut across the lines of force from both pole pieces, causing a number of interlinkages equal to the lines from one pole multiplied by the number of poles, if leakage is neglected. The interlinkages times the revolutions per second

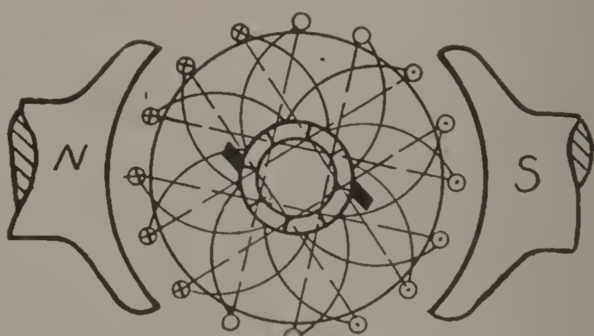


FIG. 131.

gives the rate per second at which each conductor is cutting lines, and the quotient obtained by dividing this quantity by 100,000,000 is the volts being induced in each conductor. If we multiply the volts per conductor by the number of conductors, we get the total voltage induced in all the armature winding, and by dividing this total by the number of circuits or groups of conductors in parallel, we obtain the pressure at the brushes. The following

formula can be used to calculate the voltage generated by any direct-current machine:

$$\text{Volts} = \frac{N \times P \times \varphi \times \text{R.P.S.}}{C \times 100{,}000{,}000}$$

where

N = Number of armature conductors.
P = Number of poles.
φ = Flux or number of lines per pole.
R.P.S. = Revolutions per second.
C = Number of parallel circuits in armature winding.

In expressing this formula, 10^8 is often used in place of 100,000,000 (see foot-note) and for R.P.S. is substituted $\frac{\text{R.P.M.}}{60}$. With these changes the formula becomes:

$$\text{Volts} = \frac{N \times P \times \varphi \times \text{R.P.M.}}{C \times 10^8 \times 60}$$

The voltage of an operating dynamo may be varied by a change in the speed or the field strength. In ordinary cases, where engines, turbines or water-wheels are employed to drive dynamos, the speed is practically fixed. The easiest and most convenient method for obtaining different voltages is by field regulation. This is accomplished by inserting resistance in series with the field windings. As resistance is put in, the current in the field circuit is decreased, causing a corresponding decrease in the field strength and falling off in the voltage, or

10^8 (read "10 to the eighth power") means 10 multiplied by itself 7 times, or $10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$. Also 10^{-8} (read "10 to the minus eight power") would mean 1 divided by 10^8, or

$$\frac{1}{10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10}.$$

on the other hand, the voltage can be increased by cutting out resistance, allowing more field current to flow with a corresponding increase in field strength. The adjustable resistances used for such purposes as this are called rheostats. A common form is shown in Fig. 132. By turning the handle or knob the resistance is increased or decreased, depending on the direction in which the arm is rotated over the buttons.

In building rheostats for various uses, different types of resistances are employed. In one form,

FIG. 132.—FIELD RHEOSTATS, GENERAL ELECTRIC CO.

commonly used to-day, the resistance consists merely of coiled springs of German silver or other high-resistance wire. For handling large currents, the well known grid rheostats are used, the resistance element being cast iron.

In these rheostats the covers are perforated or the supports made so as to allow a free circulation of air, for cooling. There is quite a little energy expended in any high-resistance wire or metal, as current flows, and consequently, to prevent excessive heating, a very important point in rheostat design and building is the means provided for cooling. Also, in installation, their location on switch-

board or elsewhere, should be in a position removed from any inflammable material and such that the heat radiated can do no harm.

In the so-called "pressed card" type of rheostat, the resistance wire is wound around an asbestos tube

FIG. 133.—GENERAL ELECTRIC GRID RHEOSTAT.

or cardboard cylinder, which is pressed flat and placed in rheostat.

For some purposes it is customary to employ water rheostats, consisting essentially of a box or

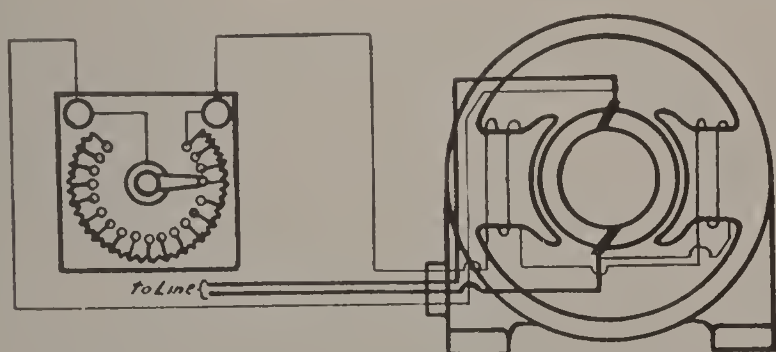


FIG. 134.—CONNECTION DIAGRAM FOR FIELD RHEOSTAT.

tank filled with water. Often the tank is of cast iron, or else the inside is lined with some metallic substance, as sheet iron. One side of the circuit is attached to this metal lining or box, the other side being connected to a movable cast-iron plate, which

can be lowered into the water to any desired depth. The resistance offered to the flow of current through this rheostat depends on the amount of the movable plate surface immersed, and on the purity of the water. If salt is added, or other impurities present in the water, its resistance will be lessened.

Fig. 134 is a connection diagram of a rheostat in the field circuit of a shunt machine for voltage regulation.

The voltage of a dynamo might be lowered by inserting resistance in series with the armature, as shown in Fig. 135, but the total line current would be carried, and the very large rheostat necessary to handle this current would be undesirable on account of bulkiness and the power consumed.

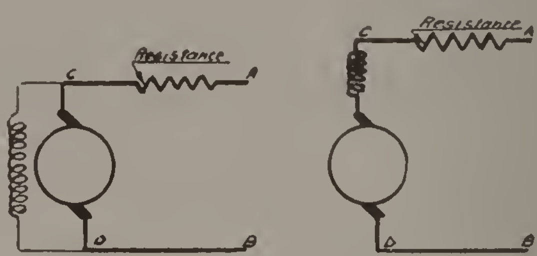


Fig. 135.—Resistance in Series with Armature.

Up to the present time, the self-excited machines considered have been already in operation. At the close of a day or night's run, as one of these is being shut down, its voltage will "fall off" with the dying down of the speed, becoming less and less until it is zero as the machine stops altogether. The question now arises, when we wish to start up the next time: How will voltage be produced, without using a separate exciter?

After the machine is shut down and the field current turned off, the pole pieces do not lose quite all of their magnetism. These magnetic lines, still residing in the pole pieces, are commonly called the **residual magnetism,** and although comparatively few in number they ordinarily are sufficient for the

purpose of building up the voltage during the subsequent starting of the machine. As the armature begins to turn in this residual field, a small voltage is induced in the conductors. This causes, in turn, a small current to flow through the field windings, augmenting the residual and inducing correspondingly more voltage in the armature conductors. In this way the voltage is brought to normal.

A necessary precaution in this proceeding, is to be sure the field coils are connected properly with respect to armature. If, after a machine is shut down, someone reversed the field wires to the armature, the small initial voltage induced by the residual would send a current through the field windings in such a direction as to buck and neutralize the residual, leaving the pole pieces with no magnetism whatever. In this state it would be necessary to use a separate exciter or some batteries to set up a few initial lines of force.

CHAPTER XV

ELECTRIC MOTORS

Cause for Rotation.

The dictionary defines Motor as **a machine which does work.** Under this classification an electric motor would be a **machine doing work and operated by electricity.** Many of the applications of electric motors are familiar to all, such as their use on street cars, elevators, in machine shops, operating ventilating fans, sewing machines, ice cream freezers, milk separators and countless other uses. There

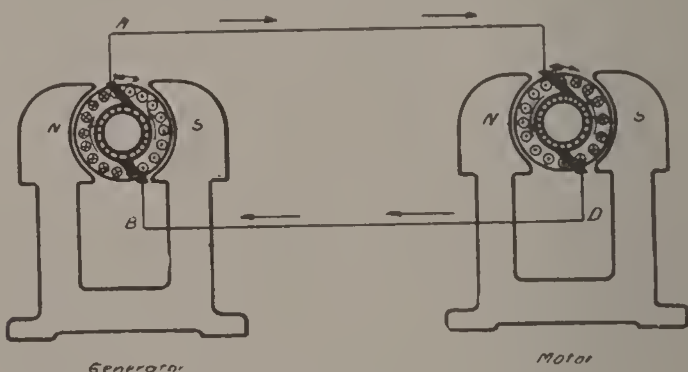


FIG. 136.

are several kinds of electric motors. Each type, owing to its distinguishing characteristics, is especially adapted for certain purposes and should be used where these particular features can be employed to the best advantage.

Any ordinary dynamo or generator capable of producing current can be operated as a motor if connected to a source of electric current. The force causing the motor armature to rotate is due to the

reaction upon the magnetic field by the currents in the armature conductors. Referring to Figs. 137, 138 and 140, the conductor carrying current towards the observer or upwards through the paper sets up circular lines of force in a counter-clockwise direction, and if placed in a magnetic field the whirls produced by the current will combine with the field from the magnet, distorting and causing the lines of force to

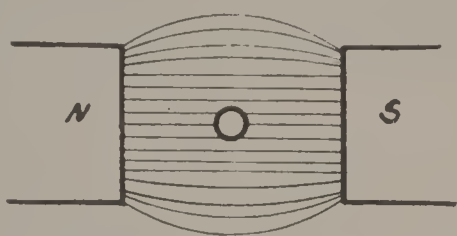


Fig. 137.—Conductor in Magnetic Field, No Current Flowing.

assume curved shapes as shown. The tendency of lines of force to follow the shortest, or path of least resistance, causes them to have a contracting action like stretched rubber bands, and there will be a

Fig. 138.—Magnetic Field around Conductor with Current Flowing Toward Observer.

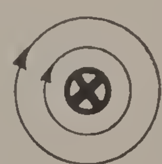


Fig. 139.—Magnetic Field around Conductor with Current Flowing From Observer.

resulting force tending to push the conductor in the direction indicated by the arrow.

If the direction of a current in a conductor is downwards or away from the reader, the resulting whirls will be in a clockwise direction, and if placed

in a magnetic field the force resulting will tend to cause the movement of the wire as shown in Fig. 141.

This force is proportional to the current in the conductor and the magnetic density, in lines per square inch.

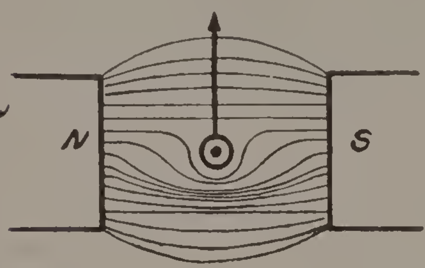


Fig. 140.

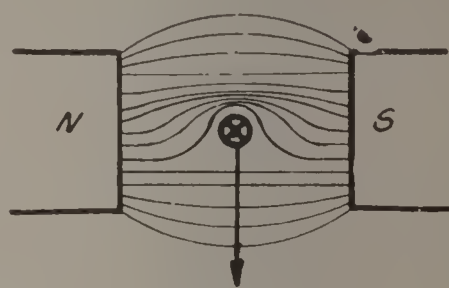


Fig. 141.

Conductor Carrying Current in Magnetic Field, Showing Distortion of Field and Direction of Resulting Push on the Conductor.

If a coil of a single turn is placed in a magnetic field as shown in Fig. 142 there will be a tendency for it to rotate in a clockwise direction if current flows as indicated. If the direction of flow of current

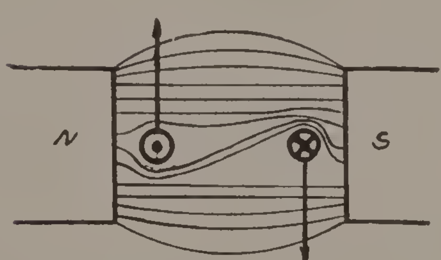


Fig. 142.

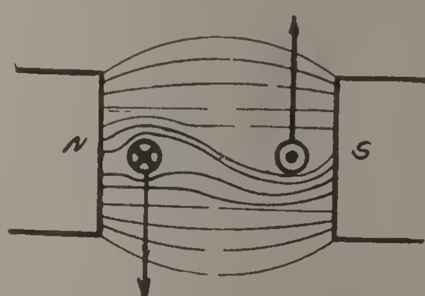


Fig. 143.

Current-Carrying Loop or Coil in a Magnetic Field, Showing Direction of the Tendency to Rotate.

is reversed in this coil, the polarity of the field remaining the same meanwhile, the direction of the rotation is reversed.

In an ordinary machine, if the armature is connected to a circuit and current allowed to flow, all

of the conductors under the north pole will carry currents flowing in the same direction, and all of the currents under each south pole will form a broad sheet of parallel currents, but flowing in an opposite direction. If the field coils are magnetized in this machine while current is flowing through the armature, rotation will be caused.

The torque, that is, the turning effort or force tending to produce rotation, in any motor is proportional to the armature current, the strength of magnetic field and the number of armature conductors.

The direction of rotation in any direct-current motor will be changed if the current flowing through the armature is reversed, provided that the polarity of the fields remain the same. If both the field magnetism and direction of armature current are reversed, the motor will continue to operate in the same direction.

CHAPTER XVI

ELECTRIC MOTORS (*Continued*)

Armature Drop — Back Electro-Motive Force — Discussion of These Two Quantities and of the Fact that Their Sum Equals Line Voltage — Starting.

Suppose the resistance of a shunt motor armature is known to be .15 of an ohm. This figure does not represent the whole winding in series, but the effective resistance offered to the flow of current through the armature from the positive to the negative brush, or in other words, the resulting resistance of the parallel circuits in the winding. If the motor was operating free, with the armature leads connected directly across a 115-volt line, it would at first seem, from Ohm's Law, that the armature current would be 767 amperes, as follows:

$$\text{Current} = \frac{\text{Volts}}{\text{Resistance}} = \frac{115}{.15} = 767.$$

But as a matter of fact, in actual tests on a 5 H.P. motor with an armature of the above resistance, the free current is approximately 5 amperes. Under ordinary conditions .75 volts would cause 5 amperes to flow through a resistance of .15 ohms, while here we have 115 volts, and can only account, apparently, for .75 volts. The question is: What has become of the other 114.25 volts?

As a motor armature rotates there is an E.M.F. induced in each of the conductors; this is necessarily so, as they are cutting lines of force from the field

magnets. These voltages, as can be seen from Fig. 136, are opposite in direction to the line voltage and will buck against and neutralize a certain portion of it, depending on the strength of the magnetic field of the motor and on its speed of rotation. It will be noted that the voltage in the generator is in the same direction as the current, while the voltage induced in the armature conductors of the motor opposes the flow of armature current. Thus if a motor is running at certain speed, such as to generate 114.25 volts, this counter electro-motive force will neutralize an equal amount of the line voltage and leave only .75 volts effective for causing current to flow. The sum of the armature-resistance drop in volts and the back E.M.F. of a motor equals the line voltage, which can be expressed as a formula:

Line Volts = Armature Resist. Drop + Back E.M.F.

$$= R_a C_a + V_m.$$

Where R_a = Armature effective resistance.
C_a = Armature current (total).
V_m = Back E.M.F. or voltage generated by motor.

To drive a machine, such as a lathe, the torque or turning effort required will depend on the work being done. A motor-driven lathe operating free requires small torque. As the tool commences to cut, thereby putting on load, the torque is insufficient and the motor speed will be lowered. As the motor slows down, the counter E.M.F. is decreased and more current will consequently flow through the armature, increasing the torque and enabling the motor to pull a heavier load than before. On the other hand, if the load on a motor is lightened, it will speed up, increasing the back E.M.F. With the consequent cutting down of the armature current the torque decreases until equilibrium is restored and the speed becomes constant.

Thus a motor is, to a certain extent, automatic in its action — more current flowing as the load increases and smaller currents passing through the machine under lighter loads. In steam engines a governor is required to regulate and admit the proper amount of steam to the cylinder with each stroke of the piston. This phenomena is taken up more fully later on and its effect upon the operation of shunt, series and compound-wound motors explained.

The free speed of the motor above mentioned was 1,500 revolutions per minute, and when delivering 5 H.P. the speed was 1,430 revolutions per minute, while the line current increased from 5 to 40 amperes. Under the loaded conditions the armature resistance drop would be $40 \times .15 = 6$ volts, and the counter E.M.F. would then necessarily be decreased to 109 volts. Also it will be noted that the speed decreased in proportion:

$$\frac{1500}{1430} = \frac{115}{109}.$$

In the case of series motors, however, this speed variation due to changes in load, gives rise to dangerous effects. If the load is quickly taken off a series motor in operation it will at once speed up. This higher speed raises the back E.M.F. and cuts down the current through armature and fields. This decrease in current weakens the field, and the motor speed continues to rise, in an endeavor to maintain the proper back E.M.F. This produces the well known tendency of series motors to "run away" and is the reason why they should always be geared to load instead of belting or other means more or less likely to give away and remove the load from motor.

In any motor, if the strength of the field is altered the speed will be affected. With a decrease

in field, the back E.M.F. is lessened temporarily allowing more current to flow through the armature circuit, and in ordinary cases, where the load is not excessive, causing the speed to rise. If we continue to lessen the field current the speed will rise higher and higher, and finally as the field current is brought to zero, the speed of the motor will have to become infinite in order to generate a sufficient back E.M.F. For this reason it is very dangèrous and disastrous if the field circuit is broken while a shunt motor is in operation, the excessive currents burning the commutator surface and usually flashing over from brush to brush. In a series motor, opening the field circuit will of course shut off current from the armature.

On the other hand, any increase or strengthening of the field in a motor will cause it to slow down. This is due to the fact that as the field is made stronger the counter E.M.F. becomes greater, temporarily cutting down the armature current to a smaller value and lowering the torque or turning effort. This will cause the motor to slow down in the course of a short period of time. However, in the special case where the armature is large and heavy, its momentum might be sufficient to momentarily generate a counter E.M.F. equal to the line voltage, or possibly even greater. If the counter E.M.F. is the greater it will actually overcome the line voltage and force or pump current back into the line, the motor acting temporarily as a generator. Motor control and speed regulation is taken up more fully in the following chapters.

If a shunt motor at rest was thrown directly across the line there would be no counter E.M.F., hence, an enormous current would flow through the armature windings, causing severe heating and flashing at the brushes, and in some cases arcing from stud to stud, which burns the commutator and is dangerous to attendants. To prevent this, a start-

ing box is used (Fig. 144), resistance being connected in series with the armature.

In starting a shunt motor, it is of vital importance to first have the field connected across the

Fig. 144. — D.C. Motor-Starting Box, Arm in Off Position. General Electric Co.

source of current with about normal excitation. Then, the motor is started and gradually brought up to speed by slowly pulling the rheostat arm across

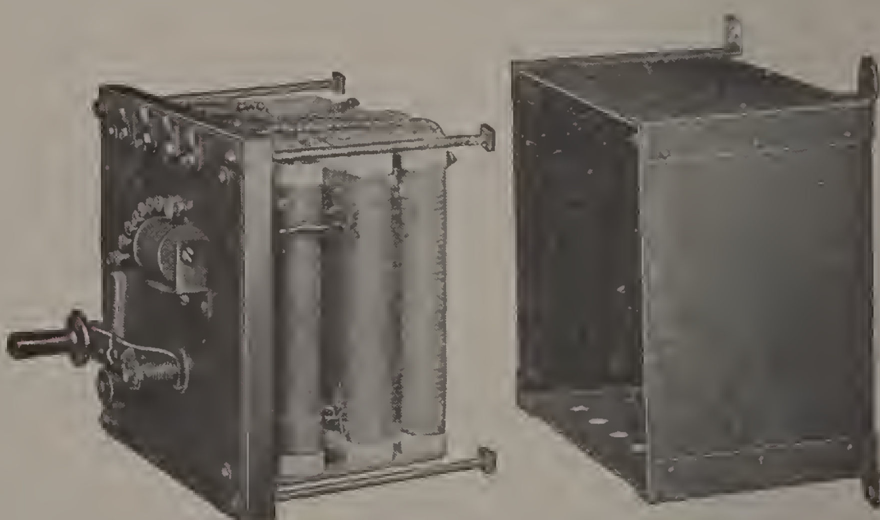


Fig. 145. — D.C. Motor-Starting Box. Cover Removed, Showing Resistance Units. General Electric Co.

the buttons, cutting out, step by step, the resistance in series with the armature (See Fig. 146).

With a series motor, a similar starting box is employed, the resistance being in series with both

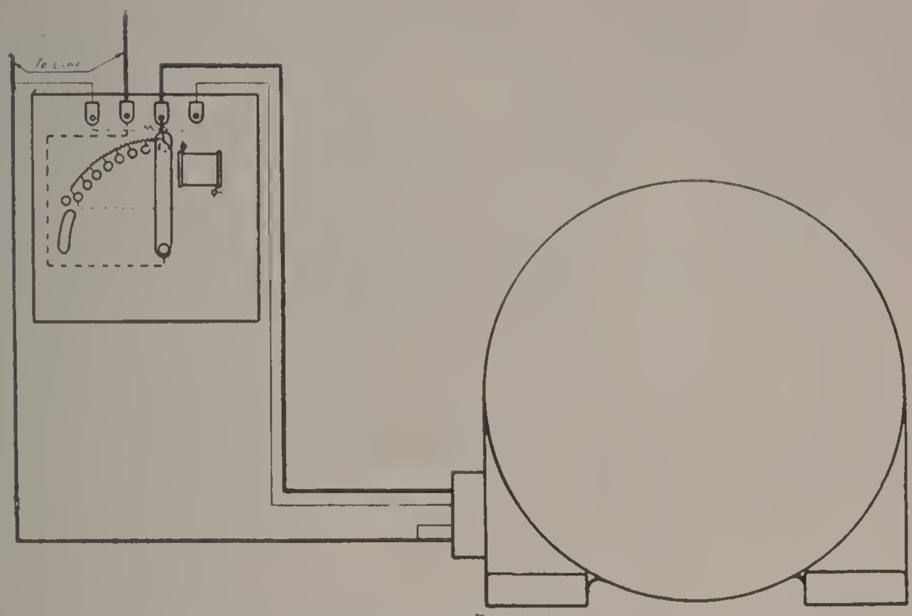


Fig. 146. — Connection Diagram, Starting Box for Shunt Motor.

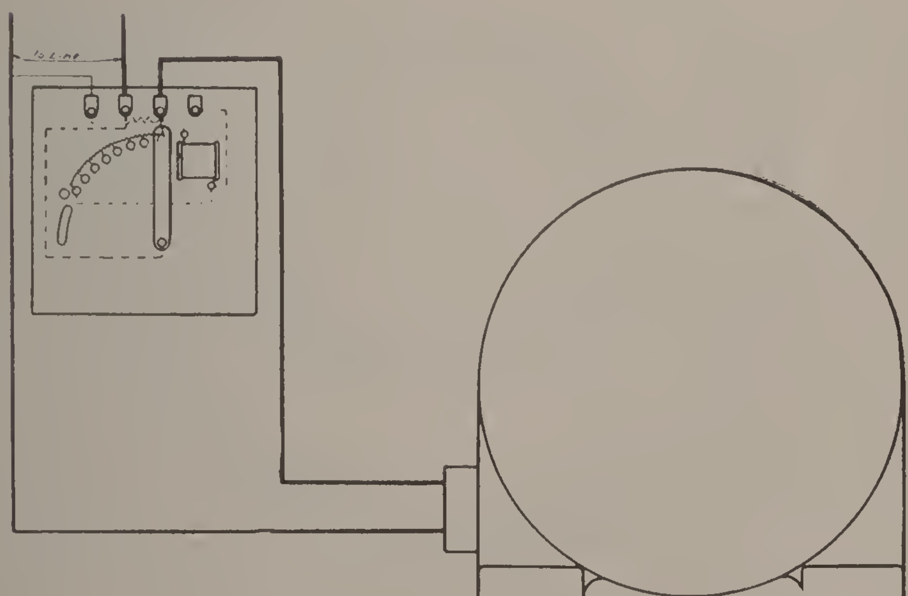


Fig. 147. — Connection Diagram, Starting Box for Series Motor.

armature and fields. A series motor is much less liable to flash over than a shunt-wound in starting, as the field is immediately strengthened whenever the current tends to become excessive. This raises

the back E.M.F. and prevents further increases in current and exerts a tendency to hold the current down to normal values. As the field of a shunt motor is approximately constant, the excitation being independent of armature current, there would not be as great a factor of safety in starting.

A second way in which the speed of motors may be varied is by inserting a rheostat in series with the armature. As the resistance is put in series with the armature, the current flows first through the rheostat and then through the armature. Due to the drop across the rheostat, the effective voltage on the armature is less, consequently the motor will slow down. This method cannot be used to raise the speed, and is rarely utilized to lower the speed, as considerable power is consumed.

CHAPTER XVII

ARMATURE REACTION

In a two-pole motor or generator the lines of magnetic force set up by main field coils will follow a path as shown in Fig. 148, providing there is no current passing through the armature conductors. The direction of flow of these lines of force of course

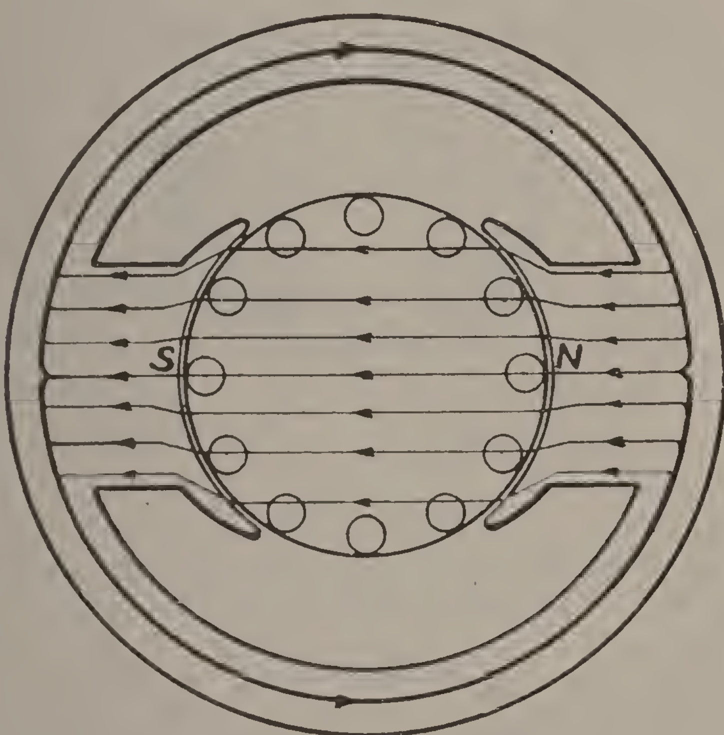


FIG. 148. — PATH OF FLUX PRODUCED BY FIELD WINDINGS, ACTING ALONE.

being determined by direction of current in field coils. On the other hand, if we omit the main field flux altogether and now consider the armature conductors carrying current as shown in Fig. 149, we find the iron core of the armature will act like a

powerful magnet, as the armature winding sets up two distinct poles, one N, the other S.

In an armature built for multipolar machines there are as many magnetic poles on the armature as there are pole pieces in the frame of the machine. These armature magnetic poles are midway between main poles of frame. In a bipolar machine the separate fields set up by the armature winding and main field are at right angles to each other. The

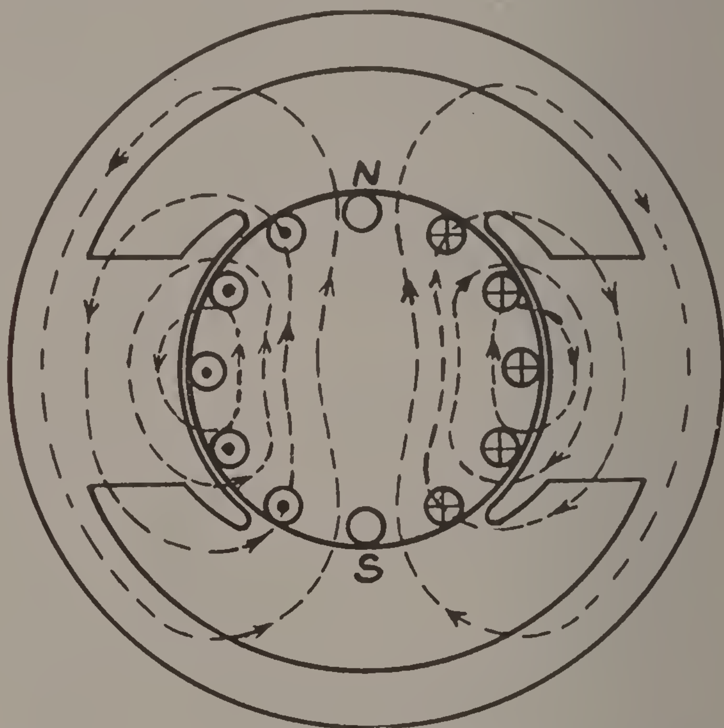


FIG. 149. — PATH OF FLUX PRODUCED BY ARMATURE CURRENT, ACTING ALONE.

combination of these two fields or resultant flux is shown in Fig. 150, the rotation of armature being clockwise. The direction of this resultant flux can be more clearly understood by noting that at pole tips A and D the main and armature fields are in the same direction and therefore augment each other, while at pole tips B and C they flow in opposite directions and oppose.

The amount of deflection of main flux depends on the relative strength of the armature and main

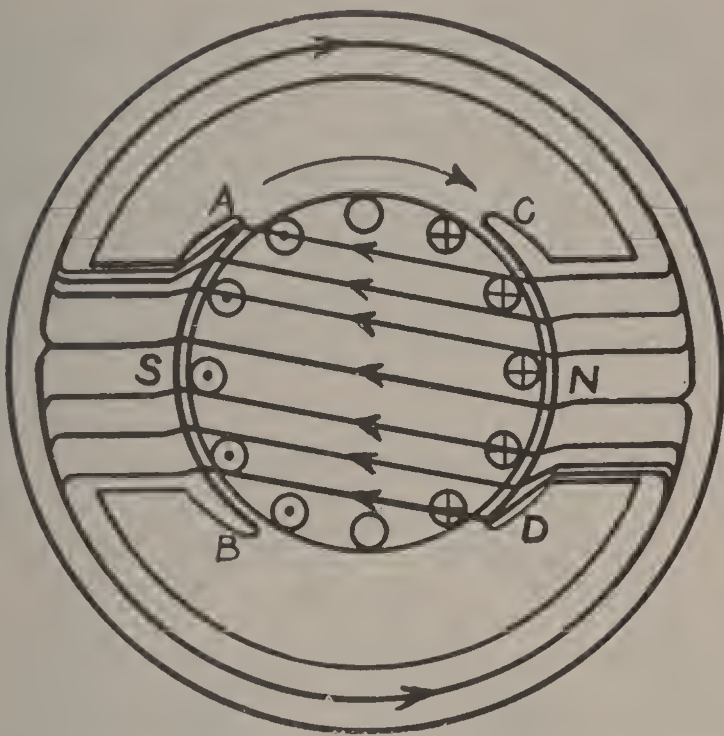


FIG. 150. — DISTORTED FIELD, RESULTING FROM THE COMBINATION OF FIELD AND ARMATURE FLUX, IN A GENERATOR.

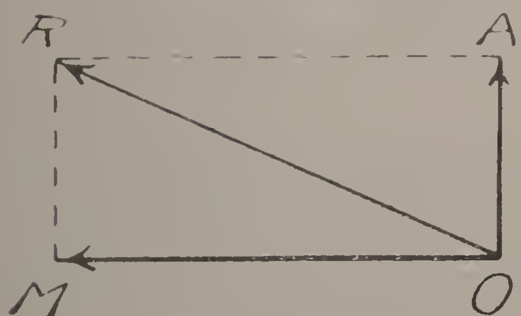


FIG. 151.

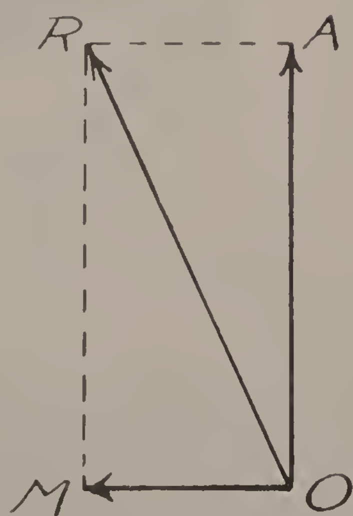


FIG. 152

DIAGRAMS SHOWING THAT AMOUNT OF DISTORTION DEPENDS ON RELATIVE STRENGTH OF THE TWO FIELDS, AND THAT WEAK ARMATURE AND STRONG FIELD WILL CAUSE LITTLE DISTORTION AS ARAMTURE CURRENT VARIES.

fields. If the main field is strong and armature field weak, any change of the amount of current in armature conductors and consequent change of armature fields causes little deflection of main flux. On the other hand, in a weak main field and strong armature any change in armature current brings about marked change in direction of resultant flux. These facts may be clearly shown in Figures 151 and 152.

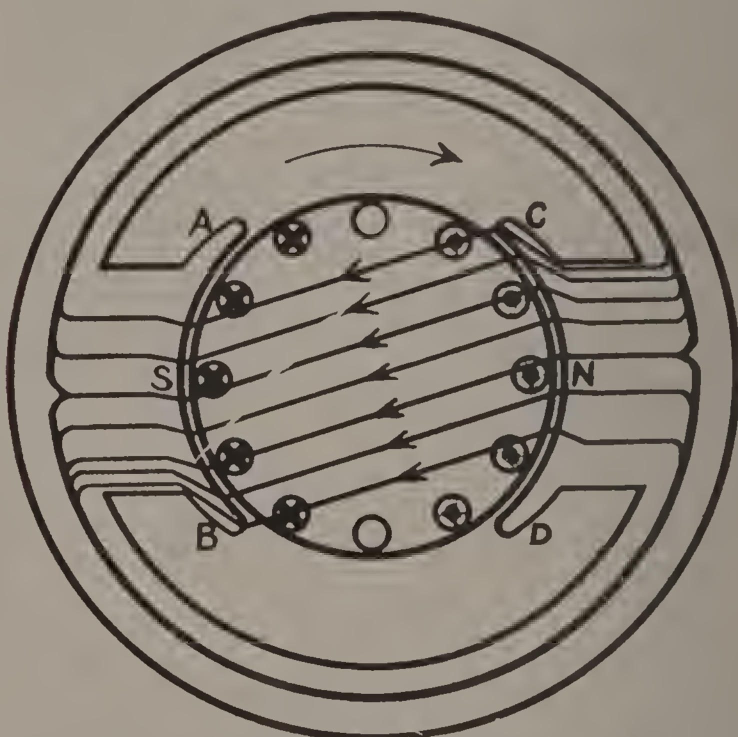


FIG. 153. — DISTORTED FIELD IN A MOTOR.

In Fig. 151, let OM represent direction and magnitude of main field, while OA represents direction and magnitude of armature field, and OR direction of resultant lines of force. Any change in OA affects direction of OR very little. But in Fig. 152 any change in OA affects direction of OR very materially.

This description is based on a generator. In a motor with same polarity of main field and direction of rotation the armature current would be reversed.

This change of direction in armature current reverses the lines of force in the armature so that the resultant flux instead of being like Fig. 150 will be up and to the right as shown in Fig. 153.

Armature Reaction is the reacting effect of the current in armature conductors upon the main field, causing the distortion as explained above.

CHAPTER XVIII

ELEMENTARY IDEAS OF COMMUTATION

The direction of current in the revolving armature conductors reverses as they pass out from one pole and under the next. Due to this change, it is necessary, in order to obtain a continuous current, for leads from certain places in the armature wind-

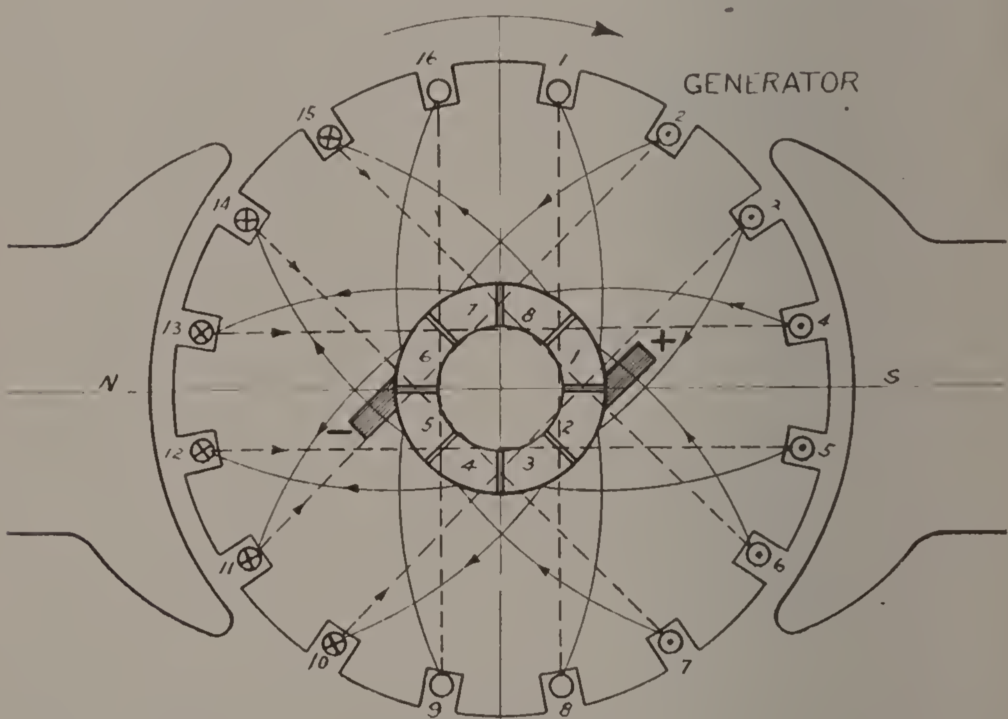


Fig. 154.

ing to be connected with a segment ring or commutator. Current is conducted to or from the commutator, as the case may be, by carbon brushes or blocks of carbon sandpapered to fit the curving surface of the commutator. These brushes, except when resting on one segment, of necessity short-circuit part of the winding, and as brushes are

generally of such width as to cover at least two segments, this short circuit always exists. Fig. 154 represents a two-pole generator, armature revolving in clockwise direction. Inspection shows that coils 1-8 and 9-16 are short-circuited by the brushes. As the armature revolves the different coils are short-circuited by brushes, but always the coils having same relation to brushes as coils 1-8 and 9-16 in Fig. 154.

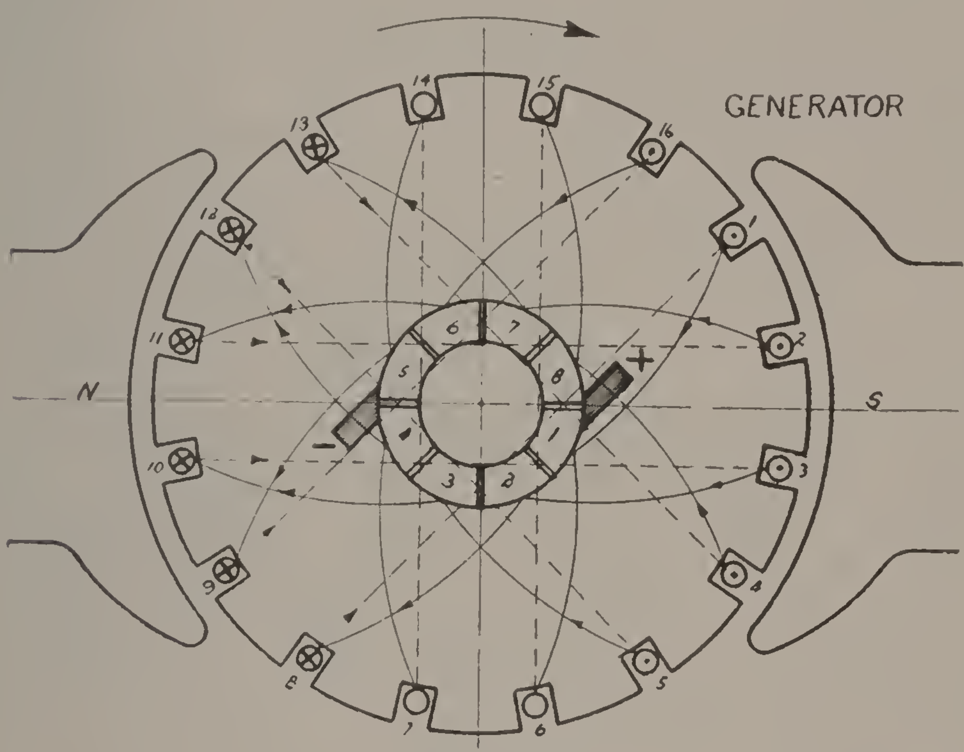


FIG. 155.

Assuming no armature current and therefore no armature reaction, the main field then flows direct from N to S pole with no distortion. As the conductors 1-8 and 9-16 are moving practically parallel to the lines of force, the voltage generated in short-circuited coils is very small. The high-resistance carbon brushes keep down what current would tend to flow in these coils.

In Fig. 154, the voltages being generated in conductors 14 and 7 are such as to cause current to flow

in directions indicated. Current flows from external circuit into brush and thence into segment 5, and from segment 5 to conductor 14. Tracing current from 14 to 7, to segment 4, and then to conductor 12, to 5, to segment 3, and then to conductor 10, to 3, and then to segment No. 2, the current leaves commutator for external circuit by means of positive brush, the voltages generated in conductors 14, 7,

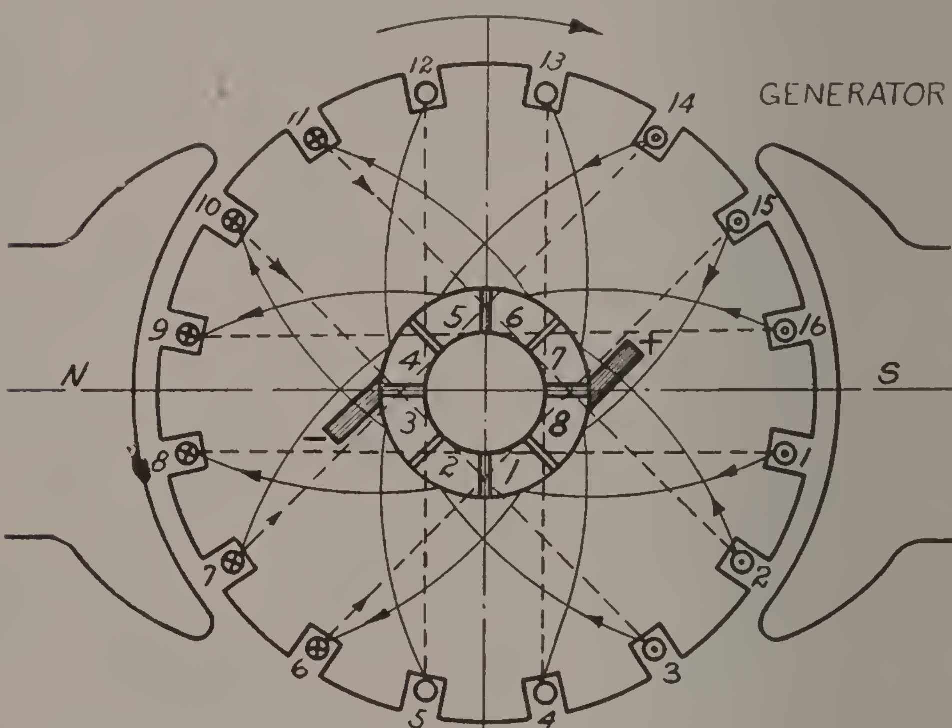


Fig. 156.

12, 5, 10 and 3 being added together. Another circuit from the negative brush exists. This is: 11-2 to 13-4 to 15-6 and from segment 1 to positive brush. The main current divides through the two circuits, one-half being carried by each circuit. The voltages being generated in conductors 2, 3, 4, 5, 6, and 7 cause current to flow toward observer at instant shown in Fig. 154, while in conductors 10, 11, 12, 13, 14 and 15 the direction is away from observer.

Fig. 155 shows armature advanced one-eighth revolution and conductors 14 and 7 are now in

neutral zone, or moving parallel to lines of force, and although short-circuited, no dangerous current will flow due to the motion parallel with the lines of force and the high resistance the carbon brushes introduce in the circuit.

In Fig. 156, an eighth of a revolution later, conductors 14 and 7 have begun to cut the lines of force again and current flows as illustrated. This will continue for another three-eighths revolution, until the coil gets to a position occupied by coil 4-13, in Fig. 156, when it is commutated once more.

It should be noted that, due to the method of connection, the voltages generated in the conductors as they sweep across pole faces are cumulative, and that while conductors are short-circuited by brushes they are moving so as to cut few lines of force and generate little or no voltage.

This discussion is based on no armature reaction, or at a condition of no load, which means little armature current for a motor and none at all for a generator. We should know, however, that when loaded, machines have armature reaction. A machine with brushes set to commutate coils midway between pole tips, as in Figs. 154, 155 and 156, would probably spark badly on heavy loads, due to currents induced in short-circuited coils by the distorted field due to armature reaction. Thus for the best commutation we must either shift the brushes, or counteract the armature reaction.

CHAPTER XIX

BRUSHES

Shifting and Setting of Brushes — Reasons for Shifting Brushes Forward from Neutral in a Generator, and Backward from Neutral in a Motor — Sparking — Interpoles.

The distortion of the field flux due to armature reaction is proportional to the current in the armature conductors. The stronger the current in the armature the greater the distortion or reaction on the field. Thus when a motor is running at light load or free, the armature current will be small and the distortion of the field will be inappreciable, while on heavy loads with the armature current increased to a large value, this distortion is sometimes very pronounced, causing the machine to spark at the brushes.

The causes for this sparking are many and varied but a few of the more important factors essential to good commutation are readily understood and will now be taken up. During the period of time a coil is short-circuited by the brush, the current must be brought to zero and then set up again in a direction opposite to that in which it was flowing before undergoing commutation. When a heavy load is put on a machine the distortion of the main field is so great as to cause a number of the lines of force to thread or interlink with the short-circuited coil. The cutting of these lines of force induces a voltage, and heavy currents will be set up, causing sparking and dangerous heating of brushes and armature. The sparking is caused by the segments con-

nected to short-circuited coils passing out from under the brush, thus breaking the short circuit. To prevent this cause of sparking the brushes should be shifted to a position where short-circuited coils will cut as little as possible of the active flux. In a generator this position is found by moving brushes forward from mechanical neutral around commutator, that is, with direction of rotation; for a motor, brushes should be moved backward. This

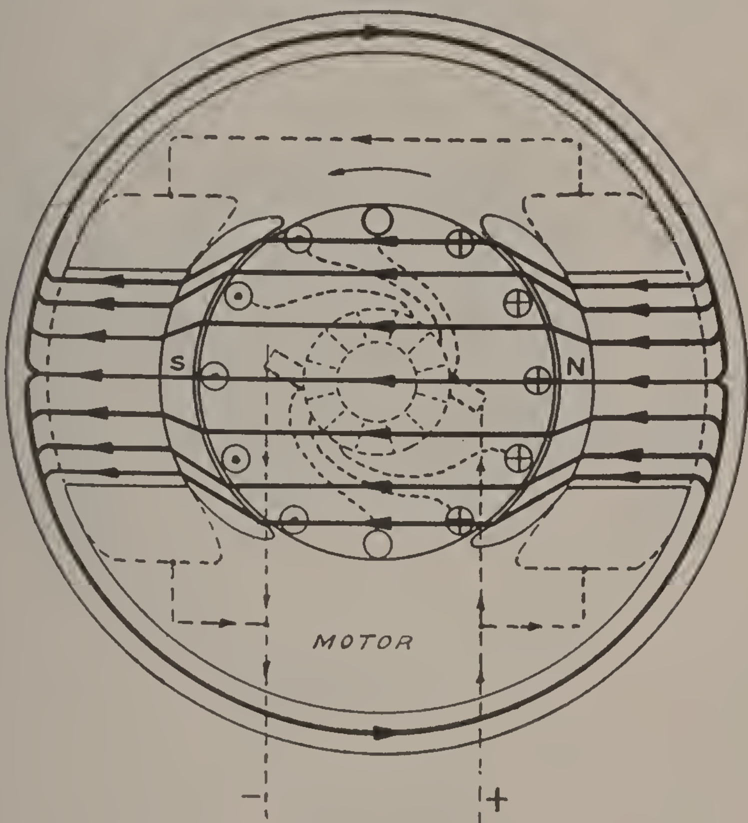


FIG. 157.

setting is called giving a generator "forward lead" or a motor "backward lead." To correctly set the brushes of a generator or motor, first trace out lead from the coil midway between pole tips to commutator segment. Then from this segment give brushes from 1 to 3 segments lead forward for generator and backward for motor, the amount of lead depending on best observed commutation results.

To more clearly show the necessity of lead in brush setting refer to Figs. 157, 158 and 159. Fig. 157 shows motor field when running at no load, Fig. 158, the full load armature field alone, and Fig. 159 the resultant field and distortion. In order to bring short-circuited conductors to a position where the flux cut during commutation will be small, it is necessary to give brushes a backward lead, sufficient

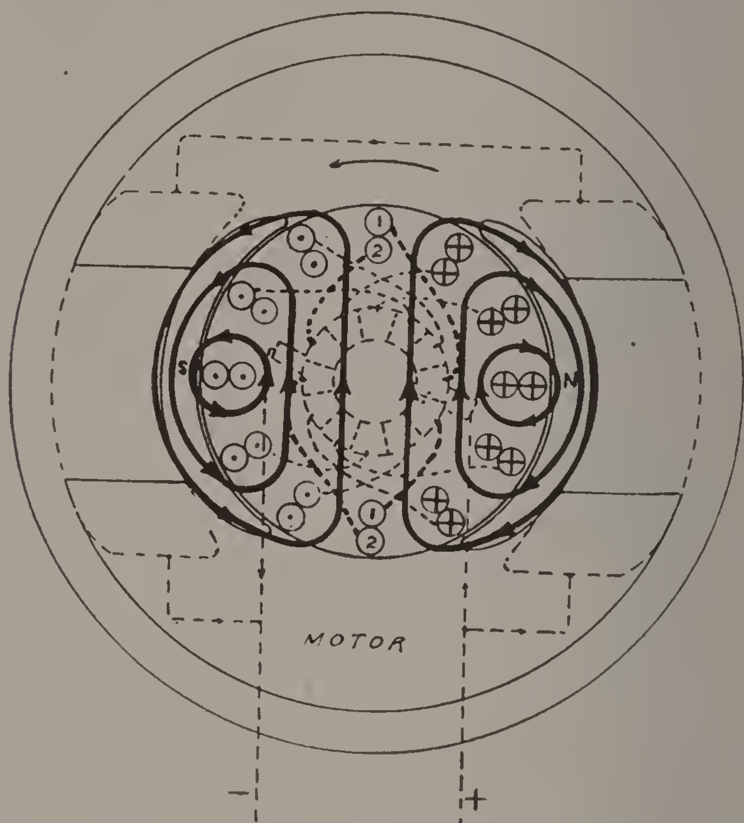


FIG. 158.

to bring conductors on line AOA. And in practice it is necessary to give brushes even a slightly greater lead than this; that is, set brushes so that commutated coils actually cut a small amount of flux from the weakened tip of the next adjacent pole, thereby inducing in short-circuited coils a small voltage which in turn tends to set up a current in conductor in *opposite direction* to the flow in coil before being short-circuited, thus not only bringing

the current to zero but actually starting a current in the reverse direction.

This extra shift of brushes is necessary because an armature is an inductive circuit. Any coil wound around an iron core is an inductive circuit and possesses the peculiar power of maintaining the flow of an electric current for a short time after the supply voltage is shut off. When an armature coil is short-circuited it is of course isolated from an ex-

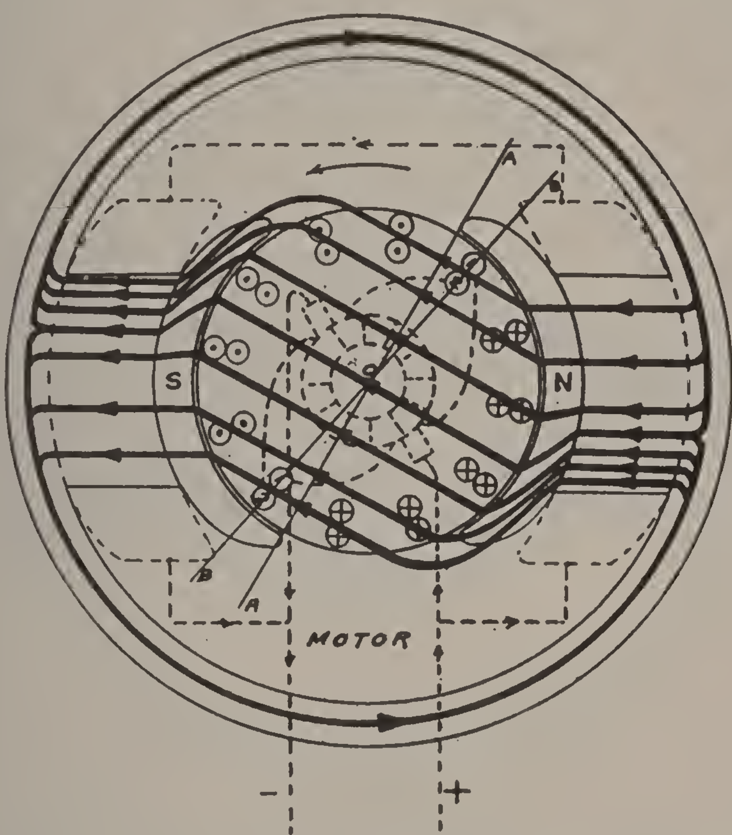


FIG. 159.

ternal source of current. The current flowing in these coils when short-circuited does not immediately die but consumes an appreciable time, and while this time is short and but a small fraction of a second, it is in many cases sufficiently great for the coil still carrying some of this inductive current to pass through the commutating zone and enter the circuit again, when it will begin to receive current from the line in the opposite direction.

The line current and the inductive current are flowing in opposite directions. As the coil emerges from the short-circuit region, still carrying inductive current, there is a resulting opposition which accentuates the sparking. It is, therefore, necessary to place the short-circuited conductors in a position of active flux so as to generate sufficient voltage not only to oppose the inductive current but to

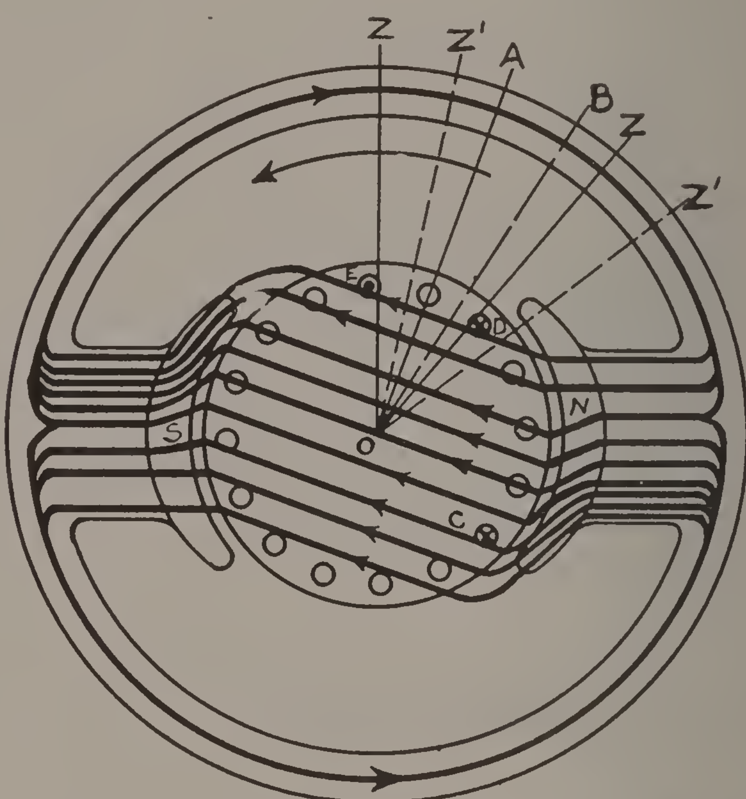


Fig. 160. — Commutating Zone in a Motor.

completely reverse the direction of the current in the conductor as it passes from one side of the commutating zone to the other.

In Fig. 160 consider conductor C revolving as shown. When it reaches D it is about to enter the commutating zone ZOZ or that part of its revolution when it is short-circuited by one of the brushes. As soon as it has reached the position E the coil must take current in the opposite direction. If now the

inductive current left in a conductor while it passes through the short-circuit zone is not neutralized sparking will occur as inductive current opposes line current at E. If the brush position is changed to give a new commutating zone Z^1OZ^1, thus bringing the short-circuited conductor into active flux, a voltage will be generated in the conductor during its passage through commutating zone of such strength as to not only neutralize the inductive

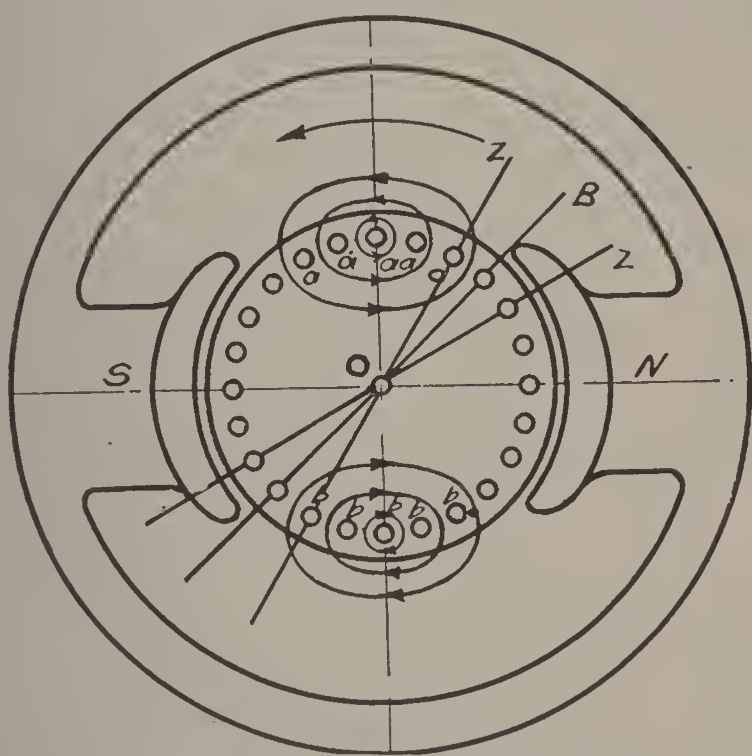


Fig. 161. — Demagnetizing Conductors in a Motor Armature.

current but actually set up a small current in the opposite direction so that conductor will take line current without opposition. This explanation applies equally well to the generator. The only difference is that a forward lead is required instead of a backward.

If a machine sparks more at no load than at full load, it indicates too much lead and brushes should be shifted to overcome this.

The backward lead on a motor causes the currents in a certain number of the conductors on the armature to set up a field in opposition to the main field thereby reducing the main flux and for this reason causing the motor to increase in speed. In a generator this same condition exists with a forward lead causing the field and consequently the voltage to be reduced. Fig. 161 shows the conductors on the armature of a motor. *ZOZ* shows

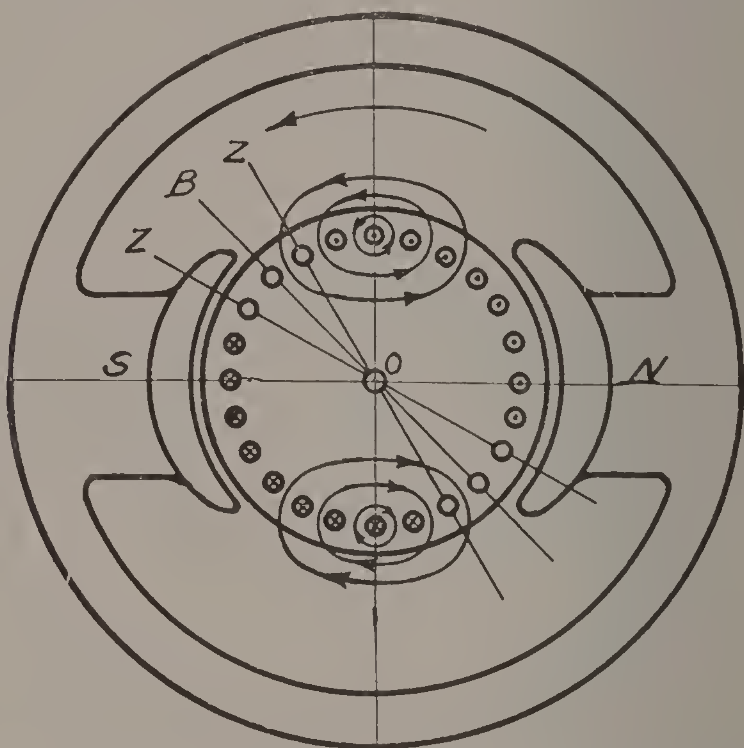


Fig. 162. — Demagnetizing Conductors in a Generator Armature.

commutating zone. Conductors *a*, *a*, *a*, etc., and *b*, *b*, *b*, etc., set up a flux in opposition to main field thereby reducing its value and speeding up motor. Fig. 162 shows same condition for a generator. These turns *a*, *a*, *a*, etc., and *b*, *b*, *b*, etc., are called "back" or "demagnetizing ampere-turns" and their number depends on amount of lead. An armature with no lead has no back ampere-turns.

Brushes should of course be made to fit commutator surface by sandpapering. Never use emery

cloth as emery is a conductor and particles remaining between commutator segments cause serious trouble by short-circuiting coils connected to the segments. Brushes are made of carbon, as has been explained, in order to introduce a high resistance between segments; and for good commutation it is necessary that these brushes should have a perfect fit on the surface of the commutator. The surface of the commutator is often rough, due to the mica insulation between the segments, which sometimes works loose and causes an uneven surface. This can be corrected by a careful application of sandpaper when commutator is revolving. It is always advisable to remove the brushes from the commutator during this process. The surface of the commutator may be so rough as to necessitate the removal of the armature to a lathe where the commutator can be tightened and its surface turned to a new finish. In some cases, particularly with large machines, it is not practical to remove the armature, and by using some standard commutator truing device a new surface can be given commutator while rotating on its own bearings.

Current density in carbon brushes should not be over 25 amperes per square inch. The density on small motors of $\frac{1}{4}$ H.P. and below is often very much less than this value as on these machines the governing factor is to have the brush large enough for ample mechanical strength and size. Copper brushes are only used on special 5 to 10-volt generators and watt-meters. These low-voltage generators are used for electroplating or in the manufacture of permanent magnets where large currents are required.

Commutating Pole Construction

In any ordinary machine not fitted with commutating poles it has been shown that a backward lead for motor and forward lead for generator is re-

quired in order to bring commutated coils into sufficient live flux to neutralize the inductive current left in the coils when they enter the commutating zone, and also to establish the small current in the opposite direction in these coils. If now this flux could be introduced midway between the pole tips no lead would be necessary for either the motor or generator, as the necessary commutating field would be found at this position rather than at a position under the main poles which necessitates a

FIG. 163.—INTER-POLE DIRECT-CURRENT MOTOR, ELECTRO-DYNAMIC CO.

lead of the brushes. Where commutating poles are used brushes would then be set to short-circuit coils midway between pole tips. Figs. 163 and 164 show a commutating pole motor. The small poles are called commutating or interpoles and are placed midway between the main poles. The field coils on these small poles are energized by the armature current and are so connected as to magnetically oppose the armature flux and so designed as to not only neutralize the armature field under the pole face but to over-balance it, thus sending into the

armature the slight amount of flux necessary to neutralize the inductive current above referred to.

As explained, the commutating coils are connected in series with the armature, therefore on light loads the commutating poles are weak while on heavy loads they are strong and at all times automatically regulate the number of lines of force passing through the short-circuited coils directly under the poles. In machines not fitted with commutating poles the theoretically correct position of setting brushes changes with the load, that is, the armature flux

Fig. 164. — Internal View of an Inter-Pole Motor.

distorts the main field more and more as the load increases, thereby requiring greater and greater lead to keep commutated coils in theoretically correct position. In the commutating-pole machine this change of lead is dispensed with as the commutating flux is supplied by the commutating poles.

Machines fitted with commutating poles can be made to operate successfully with shorter air gap between armature and pole-faces and less flux than machines not fitted with these poles. This means that motors and generators so constructed can be

made lighter and cheaper for the same output. Motors of this construction also offer better regulation, that is, the change of speed from no load to full load is less than ordinary machines, making them exceptionally desirable for driving machine tools. Figures 165 and 166 show a two and four-pole commutating pole motor.

The subject of commutating pole construction will be more fully taken up in Volume II of this

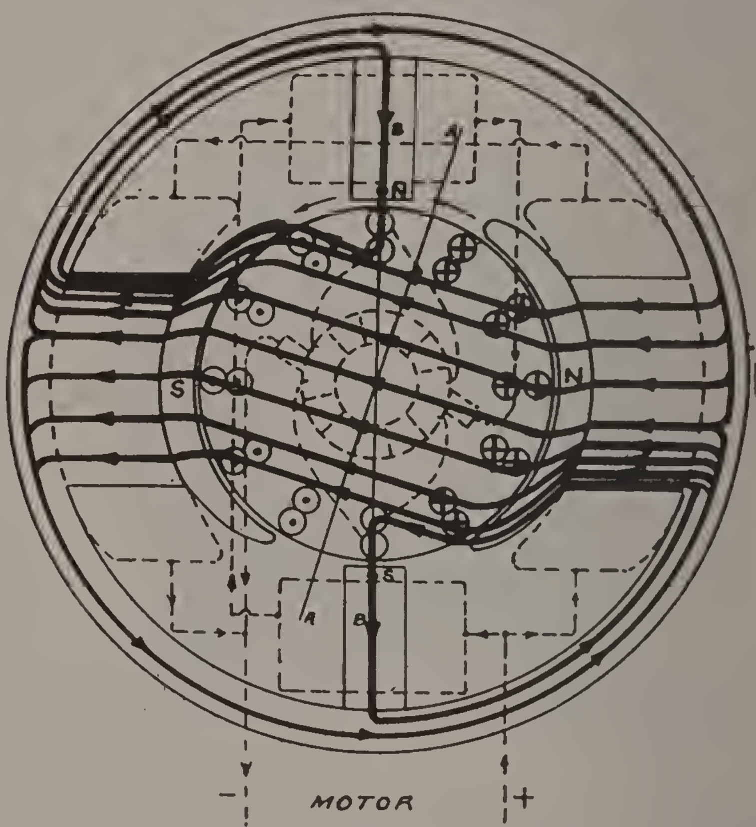


FIG. 165. — BIPOLAR INTER-POLE MOTOR. MAGNETIC FLUX DISTRIBUTION.

text-book.* Also an extract of an article by the authors in the May 5th, 1910, issue of the *Electrical World* is given below.

It is generally known that direct-current motors and generators equipped with commutating poles

* An interesting discussion of commutating poles will be found under Chapter I, Question 9, "Questions and Answers About Electrical Apparatus," by the authors.

possess many advantages over similar or old-type machines not so equipped. To equip shunt, series or compound-wound, direct-current motors and generators with commutating poles is a comparatively simple matter, and it is the purpose of this article first to show and briefly explain advantages

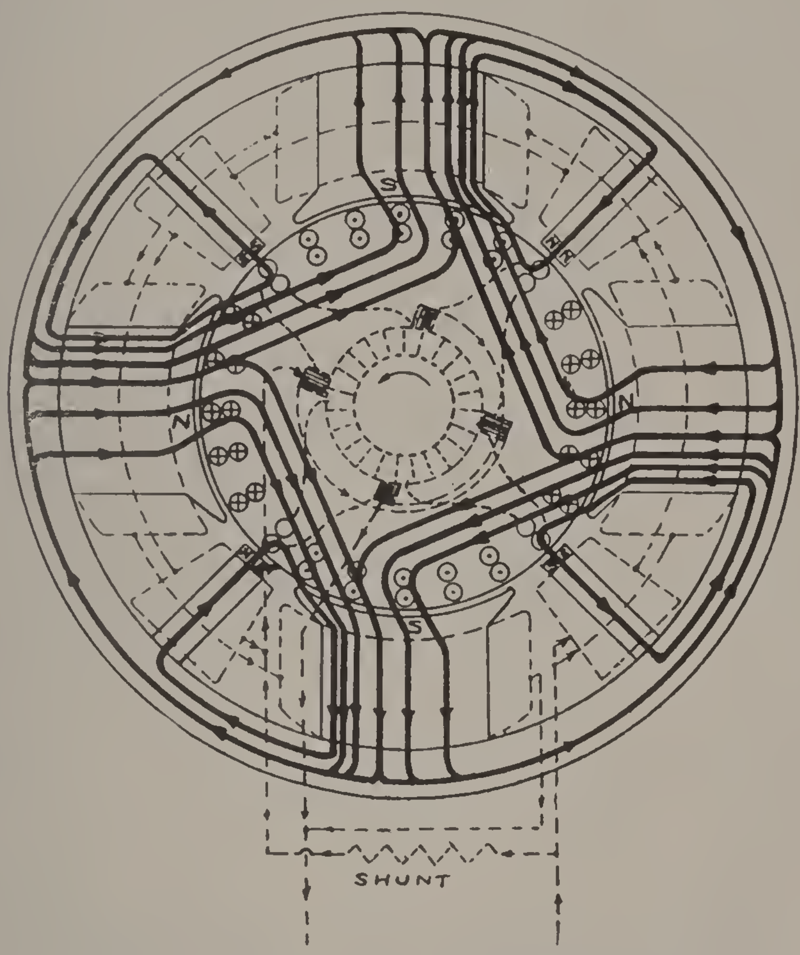


FIG. 166. — FOUR-POLE INTER-POLE MOTOR.
FLUX DISTRIBUTION.

of this construction, and then to make clear the practical calculations and applications of these auxiliary poles and coils.

The chief advantages of commutating-pole machines are high efficiency, cooler parts, improved commutation under all load conditions, and in the case of shunt motors better speed regulation.

The commutating poles, while adding to the copper losses of the machines, so reduce the short-circuited currents in the armature and brushes as to show high efficiency. The reduction in the short-circuited armature current permits not only the armature, but the commutator as well, to operate at a lower temperature. This fact renders the use of commutating poles very valuable, because hot commutators tend to cause sparking due to uneven surface and high mica.

The commutating poles should be set midway between the main poles so that their flux acts in the same capacity as the fringe of flux from the main poles previously referred to. The field coils on the auxiliary poles are connected in series with the armature in such a manner that the commutating pole flux opposes the effect of the armature reaction. The flux of the poles then increases and decreases in strength with the armature current, and is, therefore, able to offset the effect of the armature reaction under their faces which on these machines is the zone of commutation, and the brushes are always set so as to short-circuit the coils under the commutating poles. The backward motor and forward generator lead in setting the brushes is avoided. Figure 165 shows a motor fitted with commutating poles indicating the setting of the brushes.

In shunt-wound motors equipped with commutating poles the speed can be adjusted by shunting the commutating field coil current to give practically a "flat" regulation. A drop in speed from no-load to full-load of only two per cent. is perfectly feasible; closer regulations are undesirable because a commutating-pole motor becomes unstable when the speed curve is too near a horizontal line.

The commutating pole construction increases the speed of motors by from five per cent. to eight per cent. on small machines and from two per cent.

to five per cent. on larger sizes; it also lowers the voltage of generators by similar amounts. The increase of speed in motors and the decrease of voltage in generators is due to a reduction of the main flux by the interception of the commutating pole flux. The lower the main flux densities, the lower is the percentage of change.

Fig. 166 shows the flux at full load on a four-pole motor fitted with commutating poles; it should be noted that one-half of the main flux circuit is parallel to the commutating pole flux, thereby increasing the reluctance of the main flux path for that part of the circuit and consequently lowering the main flux and increasing the motor speed or lowering the generator voltage.

The Addition of Commutating Poles to Old Machines

It is a good practice to use as many commutating poles as there are main poles. The pole-pieces should be made of cast-steel forgings or sheet-steel punchings riveted together. Cast iron should not be used as its capacity for carrying flux is much less than that of steel or wrought iron. The poles should be of such length as to extend from the frame, to which they should be bolted, to the armature, leaving an air-gap not less in depth than the gap between the main poles and the armature.

The cross-sectional area of the pole is important. The thickness should be approximately three times the width of the armature slot. The width of the pole should be not less than seventy per cent. of the armature-core iron. The face of the pole need not be bored, but can be left flat. Fig. 167 illustrates these points.

The commutating pole coils should be wound with insulated wire, or bare copper wire strap with varnished cambric between layers. Terminals or ends of straps should be brought out on the ends

of the coils, not on the sides, where interference with main coils will result. Wire or strap should be wound on a suitable insulating box and then dipped in black japan. Black coils run cooler than white.

The cross-section of the wire or strap depends on the value of the armature current. The current density should be from 1250 amp. to 1350 amp. per square inch.

The formula for calculating the number of turns per coil is $T = (0.6 \times W \times S) \div (P \times C)$, where W = number of conductors per armature slot, two

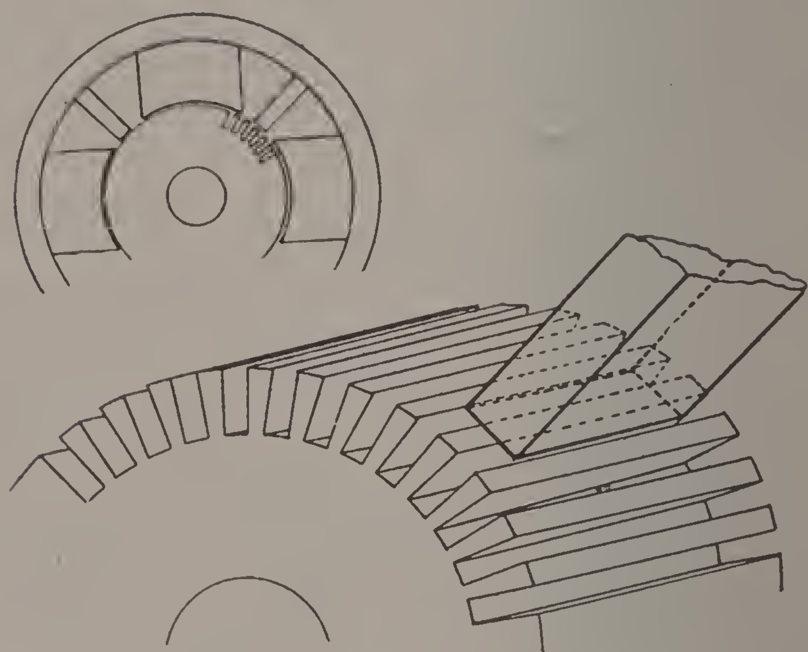


Fig. 167. — Comparative Size of Commutating Pole.

or more wires in multiple being counted as one conductor; S = number of slots; P = number of main poles; C = number of circuits in armature. $C = 2$ for all series-connected armatures and for multiple-connected armatures $C = P$.

As an example illustrating the use of the above formula consider a four-pole motor having fifty-nine armature slots with twenty-six conductors per slot, the armature being series-connected. Then $T = (0.6 \times 26 \times 59) \div (4 \times 2) = 115.5$.

One should always calculate to the nearest half turn. The armature current can be determined from the name-plate, which gives the value of the full-load current. For a shunt-wound motor, the armature current equals the load current less the field current. In a shunt-wound generator the armature current equals the load current plus the field current. The value of the field current can be ascertained by means of an ammeter.

After the connections have been made, the machine should be operated with a small amount of current; a pocket compass should be used to determine if the polarity is correct. The brushes should then be so set as to short-circuit the conductors under the commutating pole faces. The machine should be run as a motor, if possible, at light load, to determine the exact setting of the brushes to give the same speed in either direction of rotation. The brush position should be carefully marked, and the machine should subsequently be run with the brushes in this position. This setting of brushes should check very closely with the preliminary setting of the brushes referred to above. There should be connected a german silver shunt or water rheostat around commutating field coils, and the machine should be operated at full load and then double load if possible, the shunt being adjusted to give the best results; final adjustments should be made with the machine hot. The shunt should be arranged for the best commutation without making the machine as a motor unstable. Too much commutating-pole field flux will cause a motor to "hunt" or race. During the trial setting of a motor an attendant should always be stationed at the main switch to open the circuit at the first signs of hunting. No trouble of this kind is experienced with commutating-pole generators. After the resistance of the shunt has been adjusted a permanent shunt resistor can be made up and installed in cir-

cuit in place of the temporary shunt, or the commutating pole field coil can be removed and turns taken off to give the correct field strength. The correct number of turns can be determined from the values of the necessary current in both commutating field coils and the temporary shunt when the machine is operating at or near full load after a run of sufficient length to acquire its normal temperature. The new number of turns T_n can be calculated by means of the formula: $T_n = I_1 T \div (I_1 + I_2)$, where $I_1 =$ current in the compensating field coils, $I_2 =$ current in the shunt around these coils, and $T =$ the number of turns in one of the original coils.

As has been mentioned above, a commutating-pole motor will "hunt" if incorrectly adjusted. Hunting on all types of commutating-pole motors should be carefully guarded against, because serious injury may result, both to the attendant and to the machine, from any excessive speed resulting from the hunting action. Hunting is caused by the commutating field over-powering the main field, the motor running as a series machine with an excessive backward lead, thus causing destructive speed. In practice, fuses would protect a motor from injury, because the fuses, if of proper size, would blow from excessive current before the motor attained a destructive speed. A commutating-pole shunt motor subject to sudden heavy loads is more liable to hunt than is a similar motor subject to a steady load. A sudden load increases the commutating field suddenly, while the main field is unchanged, thereby causing an unbalancing of the fields. A motor once properly adjusted will run indefinitely with good results.

Commutators should always be turned and put in good condition when introducing the commutating-pole construction. The brushes of a commutating-pole motor should never be moved after once being set. In some special cases where a

motor runs only in one direction, a slight forward lead makes a motor more stable. The brushes of a commutating-pole generator may be moved slightly backward or forward as far as is consistent with good commutation in order to give the necessary voltage change.

The addition of commutating poles opens the way to run motors on higher speeds or generators at reduced voltage and full-load current by weakening the main field while retaining good commutation. The field of commutating-pole motors should never be weakened until two very important factors are accounted for. The armature and the commutator should be able to withstand the added centrifugal strains, and the motor should be carefully tested for hunting at the extreme weak field condition and run at not less than fifty per cent. overload. Armatures and commutators as usually constructed should not be run at a peripheral speed of over 5000 feet per minute.

When the foregoing suggestions are carefully followed, machines that have previously given trouble from poor commutation or excessive armature heating will run like new, and repay many times over the cost of adding the commutating poles by a lower energy consumption and a lessened maintenance charge.

CHAPTER XX

CURVES

How Curves are Plotted and Their Usefulness — Saturation Curves — Characteristic Curves of Shunt, Series, and Compound Wound Generators and Applications for Which Each is Particularly Adapted.

A glance at the outline of a man's face drawn on paper, tells to a large degree many things about him. So it is with an indicator card taken to test a steam engine; its curving outlines reveal to the experienced observer the inner workings of the engine showing whether or not it is running correctly and economically. Also in electrical machines curve sheets can be prepared which show a complete catalogue of the attainments of any piece of apparatus. In a motor, for example, a curve can be made to show the speed at any given load or the current for any speed, etc., and in a generator the volts at any current output or field strength. To understand the reading and drawing of these curves let us take a simple case showing the relation between kilowatts and horsepower. In this instance the curve will be a straight line. Curves drawn to show a fixed relation between two things such as kilowatts and horsepower are always straight lines.

Fig. 168 is drawn as follows: Take a sheet ruled into regular squares. Paper so prepared is called "cross section paper" and can be readily purchased; $\frac{1}{10}''$ or $\frac{1}{20}''$ squares are best, although paper is sometimes used with millimeter squares. Distances measured along the base of sheet are

called "abscissas" and distances measured in a vertical direction are called "ordinates." In Fig. 168 we call base line horsepower and vertical line kilowatts. Starting at A, horsepower is zero, therefore kilowatts are zero. A is then a point on curve as it shows a relation between horsepower and kilowatts. Now select any value for horsepower as 20, then $20 \times .746 = 14.9$ kilowatt. On the 20 H.P. line lay off 14.9 KW. and a new point B is determined. Again select 50 H.P. and lay off on this vertical line

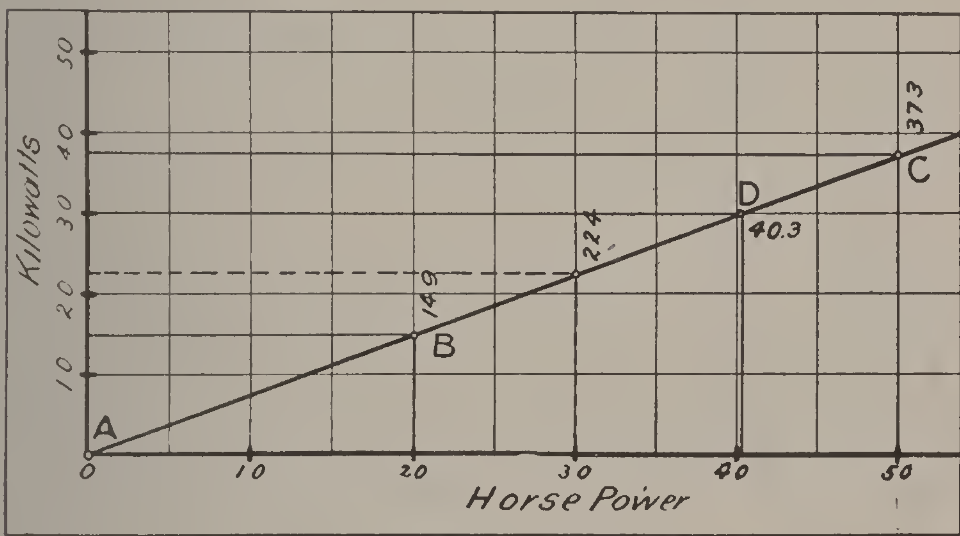


FIG. 168. — CURVE SHOWING RELATION BETWEEN HORSEPOWER AND KILOWATTS.

$50 \times .746 = 37.3$ KW. and point C is located. Again start with 30 KW. and lay off on horizontal 30 KW. line, 40.3 H.P. ($30 \div .746 = 40.3$) and still another point D is found. Joining A, B, C, and D, a curve is found which shows relation between kilowatts and horsepower, or *vice versa*. From this, values of kilowatts or horsepower can at once be interchanged. For example, to find how many kilowatts in 30 horsepower, look up 30 horsepower line until it cuts curve and note what KW. line intersects with curve at same point. In this case it is 22.4 kilowatts. This curve could just as well have been

drawn using kilowatts as abscissas and horsepower as ordinates.

Another simple case is Fig. 169 showing relation between horsepower and speed of a ship in miles per hour. It is well known that after a ship gets up to normal speed, any increase in speed requires an abnormal horsepower and consequent use of coal. In Fig. 169, the abscissas are horsepower

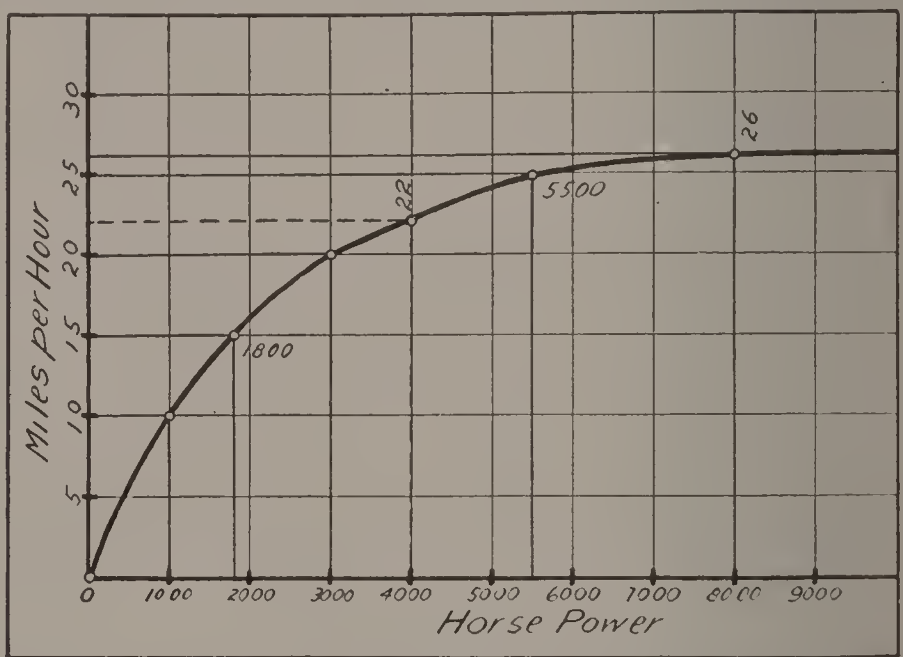


Fig. 169.—Curve Showing Relation Between the Speed of a Ship and the Power of its Engines.

and the ordinates miles per hour. Tests of a ship show the following results:

10 miles per hour	1000 Horsepower
15 " " "	1800 "
20 " " "	3000 "
25 " " "	5500 "
26 " " "	8000 "

In Fig. 169 draw the different miles per hour lines, also draw the different horsepower lines. The intersections of corresponding values will be points on curve, which shows the relation between any

speed and horsepower for this particular ship. For example, 4000 H.P. would drive this ship 22 miles per hour.

The results of the following experiment may be plotted. Arrange apparatus as shown in Fig. 170 and allow different noted currents to pass through coil, meanwhile measuring the pounds pull necessary to separate bars. Reading as follows:

Current in Amperes	Pull in pounds
1	8.5
2	13.5
3	16.5
4	18.5
5	19.6
6	20.5
7	20.6

The iron becomes saturated at about 5 amperes in coil, that is, any further increase in current to gain added magnetic effect is wasted. Laying out the results of this test is called "plotting the points." The curve, Fig. 171, shows pull for any given current, or *vice versa*. If cast iron bars were substituted in place of the mild steel the magnetic pull would be much less and would be shown by the lower curve in Fig. 171. This method of determining saturation is very crude, and more elaborate methods are resorted to in laboratory work. The reluctance or magnetic resistance of iron and steel varies with the flux density. In sheet iron or steel when density gets up to 95 or 100,000 lines per square inch and in cast iron when density reaches from 35 to 40,000 the reluctance increases very rapidly. For example, it requires twice the magnetizing energy, which means double the number of ampere turns, to force flux through a given cast steel bar at 100,000 density than for a density of 90,000. Magnetic materials are said to be saturated when the reluctance becomes excessive.

Fig. 172 shows saturation curves of a standard grade of cast steel, sheet steel and cast iron. These curves are plotted from laboratory data giving am-

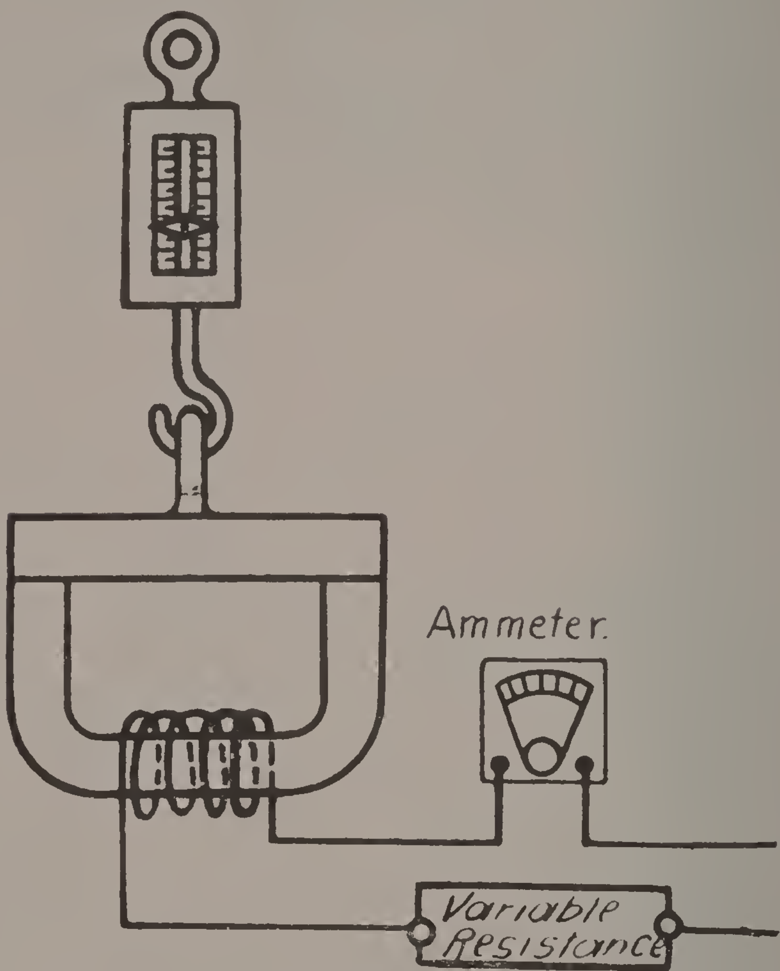


Fig. 170. — Electro-Magnet with Core and Armature of Steel or Cast Iron.

pere turns per inch length of magnetic circuit for abscissas, and number of magnetic lines of force per square inch for ordinates. In a magnetic circuit it requires a certain number of ampere turns to force a certain number of lines of force per square inch through one-inch length. For example, a cast-steel bar one inch square, four inches long, requires 26.0 ampere turns per inch to drive 80,000 lines of magnetic force through it, or a total of $26 \times 4 = 104$ ampere turns.

To drive lines of force through air requires a fixed number of ampere turns per inch for a given density. Fig. 173 shows this relation. With curves shown in Figs. 172 and 173 the ampere turns neces-

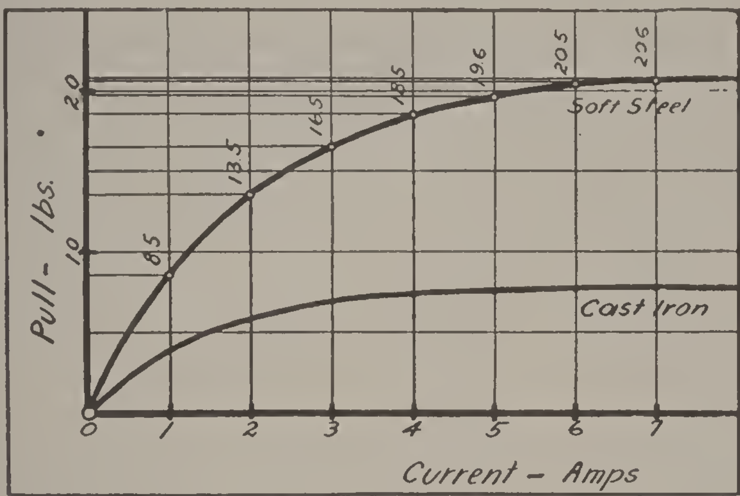


FIG. 171. — CURVES SHOWING RELATION BETWEEN CURRENT AND PULL NECESSARY TO DETACH THE ARMATURE, FOR STEEL AND CAST IRON.

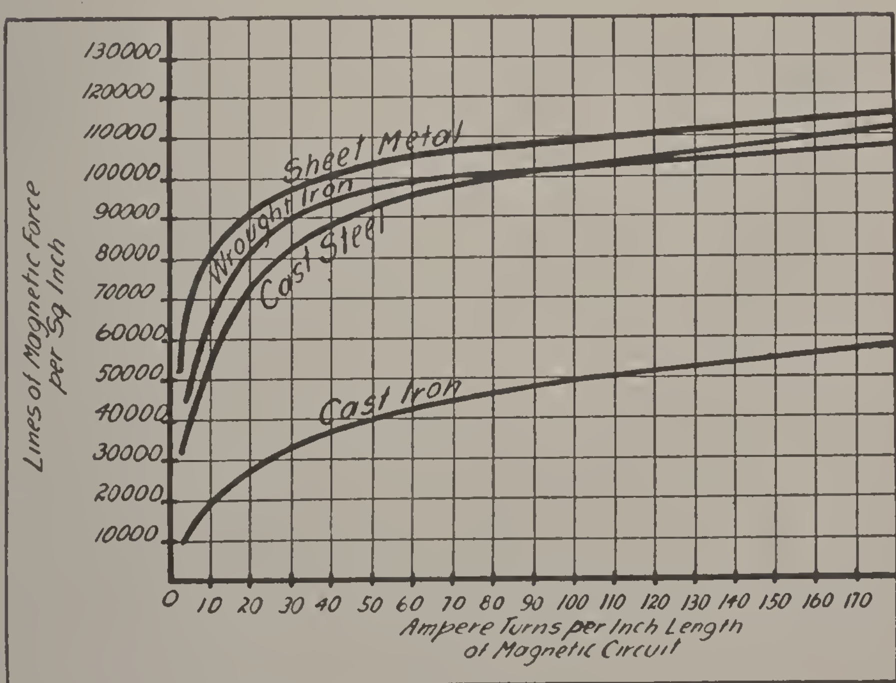


FIG. 172. — MAGNETIZATION CURVES OF WROUGHT IRON, CAST STEEL, CAST IRON, AND SHEET IRON SUCH AS USED FOR ARMATURE PUNCHINGS.

sary to drive a given flux through any magnetic circuit can be calculated.

Generators are designed to operate at approximately constant speeds, and characteristic curves of generators are generally limited to showing relation between voltage at terminals and current output.

Series generators have widely varying characteristics. Fig. 174 shows relation between amperes and volts on a series generator. Curve *OA*

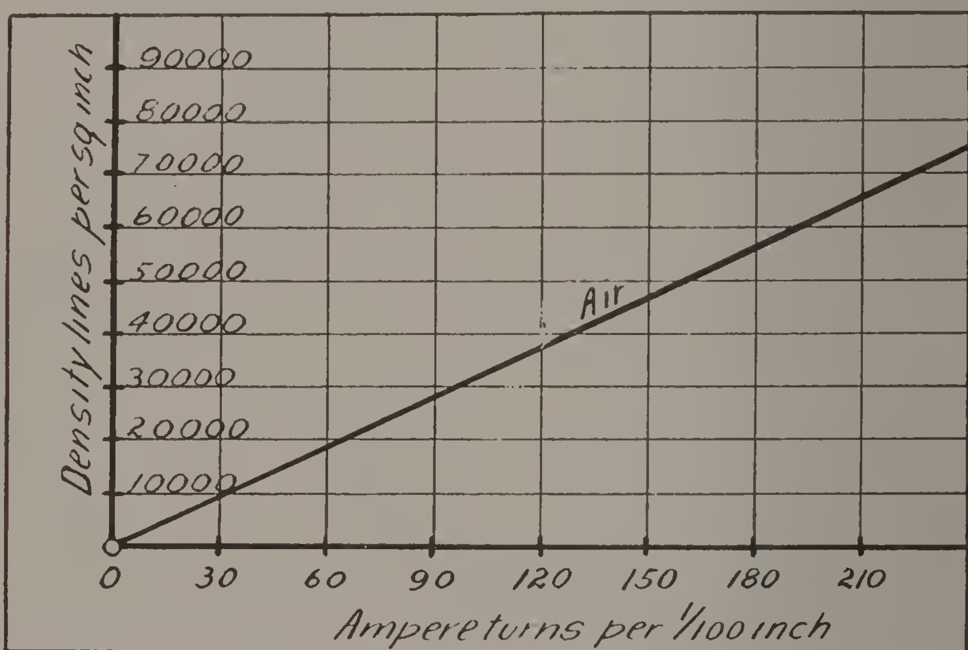


Fig. 173. — Magnetization Curve of Air.

shows voltage generated by armature, while *OB* is volts drop in armature, field and brushes, due to resistance. Subtracting *OB* from *OA* gives *OC*, the available terminal voltage. Note that the voltage of a series generator changes with load. Machines of this type when operated with external regulators can be made to give an approximately constant current for series arc lighting. This method of lighting is not so widely used as formerly. The commercial adoption of series generators is restricted, the only other use of note being their

employment as boosters, principally in street railway plants.

In Fig. 175, the booster shown is driven by a motor and in this way adds 50 volts to the generator terminal pressure.

Fig. 176 illustrates another method of connecting a booster, so that it carries only part of generator current, and provides 550 volts at the

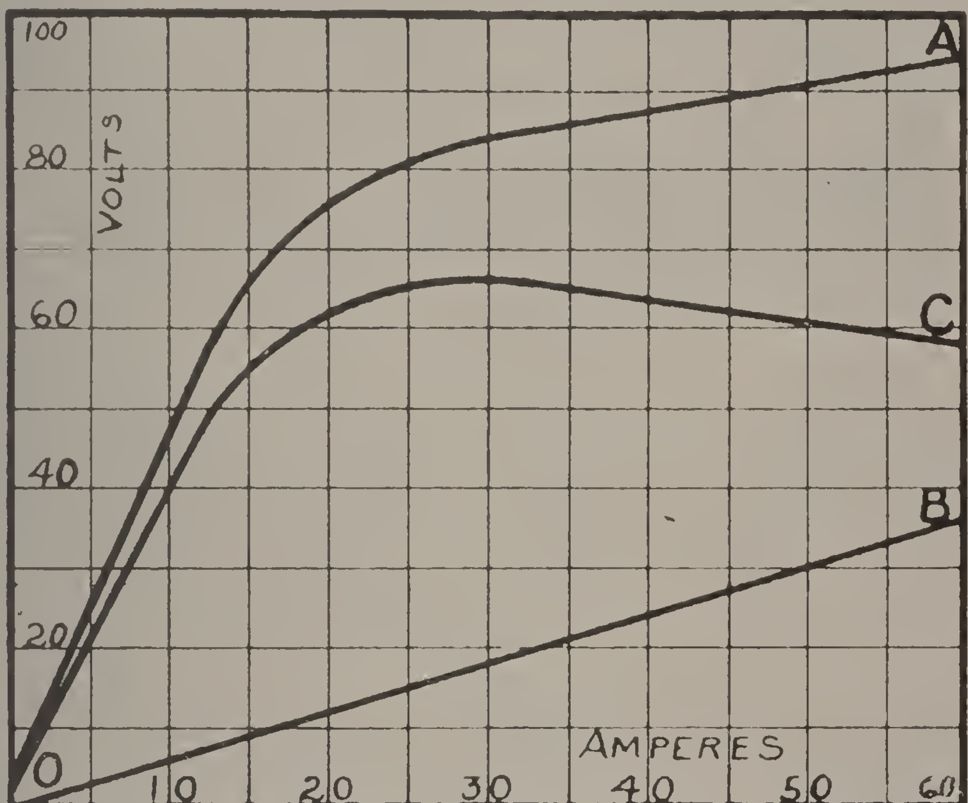


FIG. 174. — CHARACTERISTIC CURVE, SERIES GENERATOR.

end of line, making the pressure more uniform throughout the system.

Boosters should preferably be direct connected and always provided with a centrifugal shaft switch so arranged as to disconnect booster from circuit if it exceeds a certain speed. Any loss of driving power will allow the current to stop the booster, start, and drive it in the reverse direction as a motor. Without a centrifugal switch it will run away and

be thrown to pieces, being practically a 50-volt series motor without load on a 550-volt circuit.

Fig. 177 shows curves for a separately excited shunt generator. Curve *OA* represents voltage

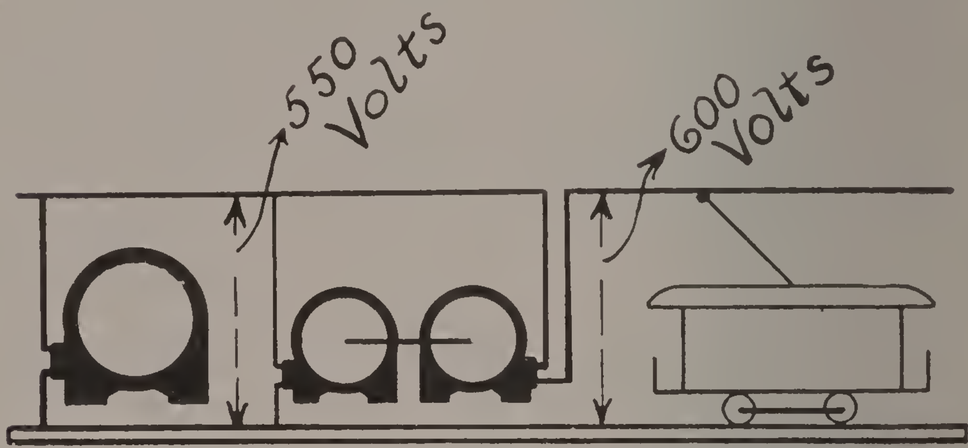


FIG. 175. — SERIES GENERATOR USED AS A "BOOSTER."

generated if no *RI* drop. Curve *OB* is *RI* drop in armature and brushes. *OC*, the difference between *OA* and *OB*, is voltage at terminals. Separately excited shunt generators are seldom used except

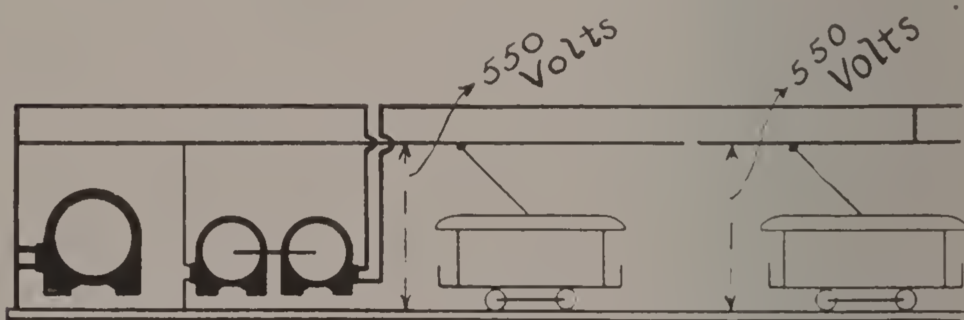


FIG. 176. — SERIES BOOSTER CONNECTED TO LONG-DISTANCE FEEDERS ONLY.

for low voltage plating work. A curve for a self-excited shunt generator is shown in Fig. 178. Note that at point *D* the field is so weakened by reduction of voltage that it ceases to supply sufficient flux to keep up voltage and generator "dies down" or

ceases to generate. In a commercial machine this falling off point is at such a heavy armature current that machine will not show this action except on dangerous overloads.

Shunt generators are used in small sizes from 3 to 5 KW. where variation of voltage due to change of load is not a detriment or where voltage can be regulated by hand. Shunt generators of

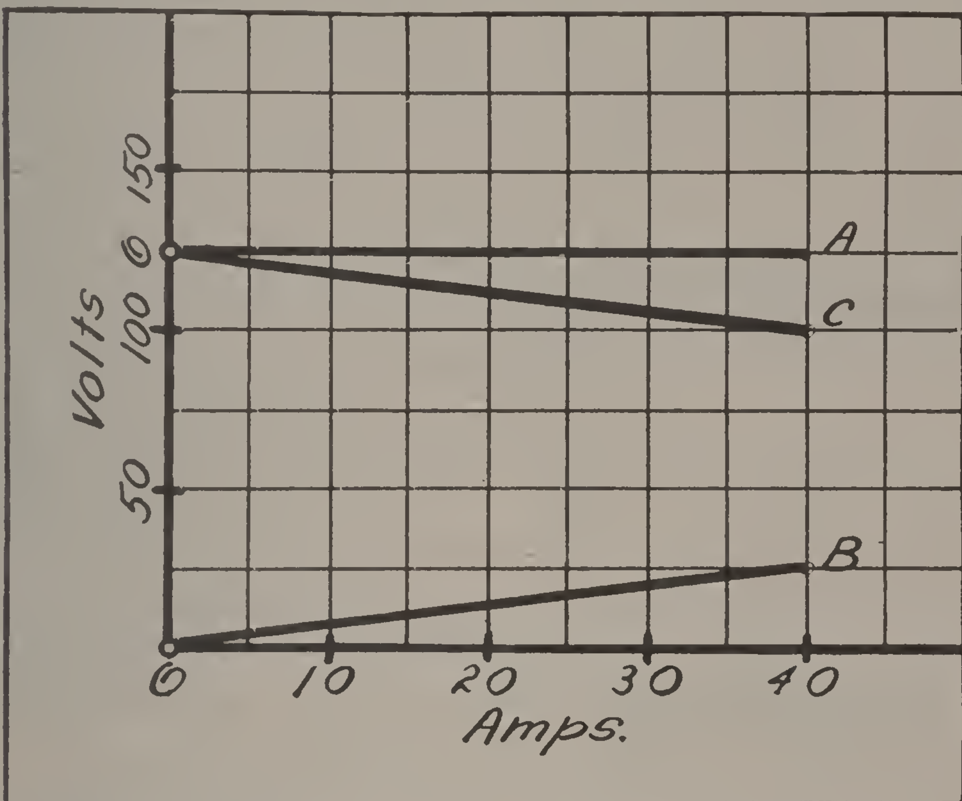


FIG. 177. — CHARACTERISTIC CURVES, SEPARATELY EXCITED GENERATOR.

larger capacity can be used on constant loads, such as hotels or large stores, where change of load is gradual, and can be met by attendant at switchboard field rheostat. Compound wound generators require no attendant at rheostat, due to their automatic regulation of voltage, except when connecting one generator in parallel with another.

In a compound generator we have a series field supplying the ampere turns lost by main shunt

field when a reduction of voltage occurs, due to RI drop in lines or the increasing armature reaction as load comes on. That is, the series winding helps out the shunt field.

In Fig. 178 OA is voltage generated by shunt field flux, assuming no RI drops, OE voltage generated by both shunt and series field flux, assuming no RI drops. If now the RI drops shown in OC be subtracted from the curve OE, a voltage OB will result. By changing the strength of series field this line OB can be made to rise or fall, that is, give a

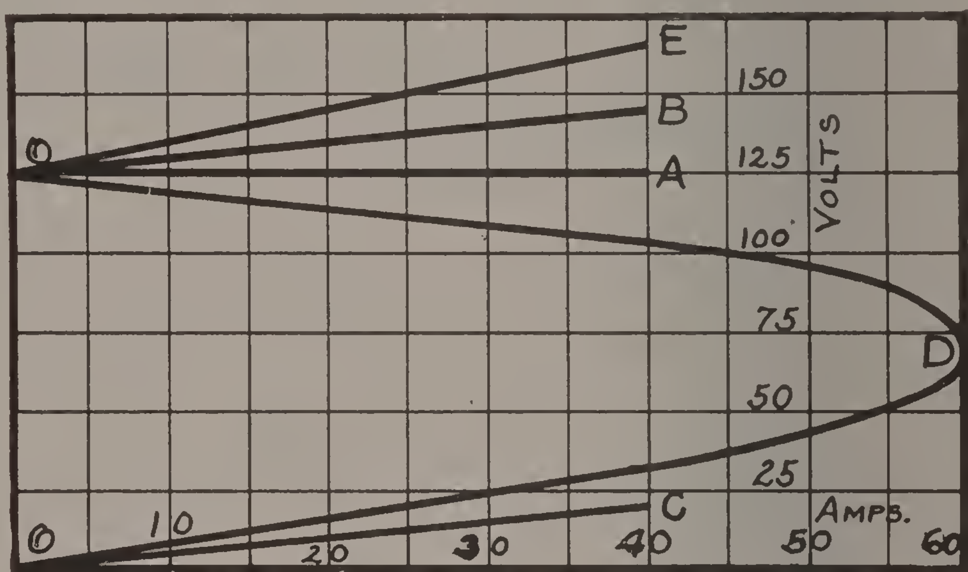


FIG. 178. — CHARACTERISTIC CURVES, SHUNT AND COMPOUND GENERATORS.

greater or less voltage as load comes on, making a "rising" or "lowering" characteristic. Compound generators are always used for supplying varying loads, as street railway service, electric elevators, etc. They are now almost universally used for all sources of direct current except for special generators, such as low voltage platers or high voltage series machines.

CHAPTER XXI

ALTERNATING CURRENTS

Explanations of Alternating Currents and Some of the Differences from Direct Current — Curves of Alternating Current — Single Phase — Polyphase — Two and Three-Phase Current — Delta and Y-Connection — Alternators.

An Alternating Current, as indicated by its name, is one that periodically alternates in its direction of flow. The nature of the alternating cur-

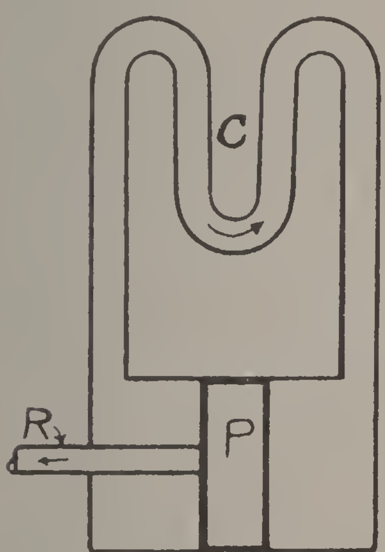


FIG. 179.

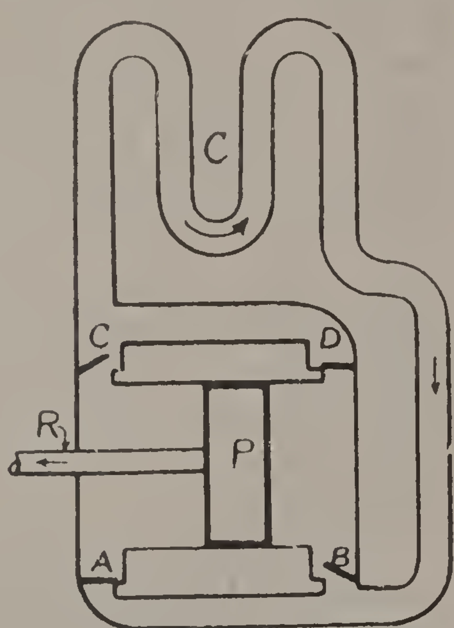


FIG. 180.

rent, especially in comparison with direct current, may well be illustrated by reference to Figs. 179 and 180.

Referring to Fig. 179, let us suppose the cylinder and coil of pipe to be filled with water, and the piston

P, actuated by the rod R, to be moved toward the left. This will cause the water to flow from the left of the cylinder into the right through the coil of pipe C in the direction indicated by the arrow.

Now let us suppose that the piston reaches the end of its travel and starts on the return stroke. Immediately the water has to flow from the right end of the cylinder to the left through the coil C in the direction opposite to that indicated by the arrow. In a similar manner, alternating current flows first in one direction and then in the other.

Now let us consider Fig. 180, which shows a similar analogy of the direct current. If the piston is moved toward the left, the valves A, B, C, and D are so arranged that B and C open and A and D close and permit the water to flow through the coil in the direction of the arrow, as in Fig. 179. When the piston starts on the return stroke, while B and C close, A and D open, permitting the water to continue to flow in the same direction through the coil C. As the action of Fig. 179 is simpler than that of Fig. 180, even so is the action of an alternating current generator simpler than that of a direct current generator; but as the characteristics of the water flowing through the coil in Fig. 179 are more complicated than those of the water flowing through coil in Fig. 180, even so the characteristics of alternating currents are more complex than those of direct current.

The valves A, B, C and D serve the same purpose in Fig. 180 as the commutator on a direct current generator. Again referring to Fig. 179, let us suppose the piston P, being at the end of its travel toward the right, to move to the end of its travel to the left, then back again to its original position at the right. The water in the coil C will have started to flow in the direction indicated by the arrow, stopped, and returned in the opposite direction until it has the position it occupied before the piston

was moved. The water may be said to have gone through a complete cycle of operations. In a similar manner when an alternating current has started at zero, reached a maximum value, decreased to zero, increased to a maximum in the opposite direction, and again returned to zero, it is said to have gone through one complete **cycle**.

The number of complete cycles through which an alternating current passes in one second is called its **frequency**.

The frequencies most commonly found in lighting and power plants in the United States are 25 and 60 cycles, although there are a few of the older stations still operated at 125 and 133 cycles, and some of the recent installations in connection with street railway work employ 15 cycles. Very much higher frequencies than these are used in wireless telegraph work.

Any conductor having a current of electricity flowing through it in a certain direction will have a magnetic field set up around it in a corresponding direction. If this current is reversed, the magnetic field will also be reversed.

Consider the piston P in Figure 179 to be moving towards the left and the water flowing through the coil C in the direction indicated by the arrow. Suppose a force be exerted on the piston rod R to force the piston P toward the right. Before P can move toward the right the force must stop the water flowing in the coil C and start it flowing in the opposite direction. The inertia of the water not only tends to prevent this but tends to keep the piston moving towards the left.

In a similar manner, the magnetic field around a conductor carrying current not only tends to prevent the reversal of that current, but to continue its flow in the same direction. Let us suppose that the piston P and the rod R are without weight, that the external force applied to R is the voltage or

pressure of the circuit, the piston P to be the current flowing and the water in C to be the magnetic field set up around the conductor due to the current flowing. Then even as the external force has to be applied to R an appreciable length of time before the direction of flow of the water in C is reversed, so the voltage or pressure of the circuit has to be applied an appreciable length of time before the current is reversed. In other words, the current **lags** behind the voltage. This tendency to keep the current flowing in the same direction is the effect of **inductance** of the circuit and has to be taken into con-

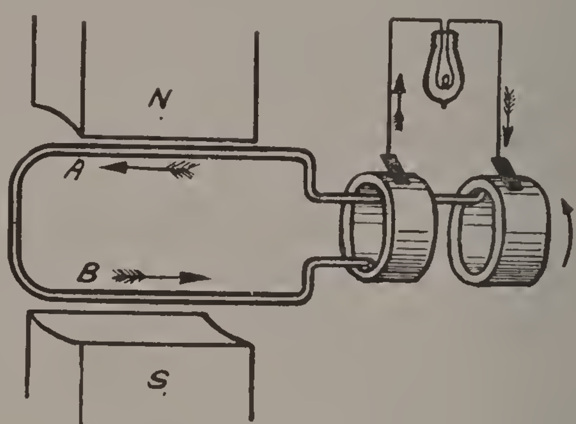


FIG. 181.

sideration in calculating line losses and the amount of voltage necessary to force a given amount of alternating current through any circuit.

As applied to direct current, Ohm's Law is $I = \frac{E}{R}$, where I is the current, E the voltage, and R the resistance of the circuit. The same law applies to the alternating current, only for R, the resistance of the circuit, we must substitute the **impedance** of the alternating current circuit, which is the combined resistance and reactance, and is represented by $\sqrt{R^2 + X^2}$, where R is the ohms resistance and X is the reactance. The **reactance**

is the inductance multiplied by a constant depending on the frequency.

Thus the law becomes $I = \dfrac{E}{\sqrt{R^2 + X^2}}$.

Where condensers are used, or the circuit is such as to give a condenser action, there is another factor affecting the flow of an alternating current. This factor is called the **condenser** or **capacity effect** of the circuit, and when it is taken into consideration

the law becomes $I = \dfrac{E}{\sqrt{R^2 + \left(X - \dfrac{1}{C}\right)^2}}$, where C is the capacity effect.

A comparison of this formula with that for direct current will give a good idea of how much more complicated the action of an alternating current appears when compared to direct.

In Fig. 181 is shown a single loop of wire arranged to conveniently revolve between the poles of a permanent magnet. This may be considered the simplest form of an alternating current generator or alternator. As the loop rotates in the direction indicated by the arrow, it will cut the lines of magnetic force between the two poles of the magnet. The induced electromotive force will tend to send a current through the loop in the direction indicated by the arrow heads on the loop.

Let us suppose that the ends of the loop are connected to collector rings; and brushes, connected externally by the wires and lamp, bear upon the collector rings. Then a complete electrical circuit will be formed through the revolving loop, the collector rings, the brushes and the external circuit. Consequently, as the loop is caused to revolve, a current will be set up in the direction indicated, which will be a maximum when the loop

is in the position shown, and will gradually decrease until the loop has passed through 90°, when the current will be zero. This may be readily understood when it is seen that at this position the sides of the loop are moving parallel to the lines of magnetic force and consequently do not cut them.

Now suppose that the loop continues to revolve in the same direction. The two sides of the loop will be cutting lines of magnetic force in the opposite direction to what they were before, consequently a current will flow through the loop in a direction opposite to that indicated by the arrow heads. This

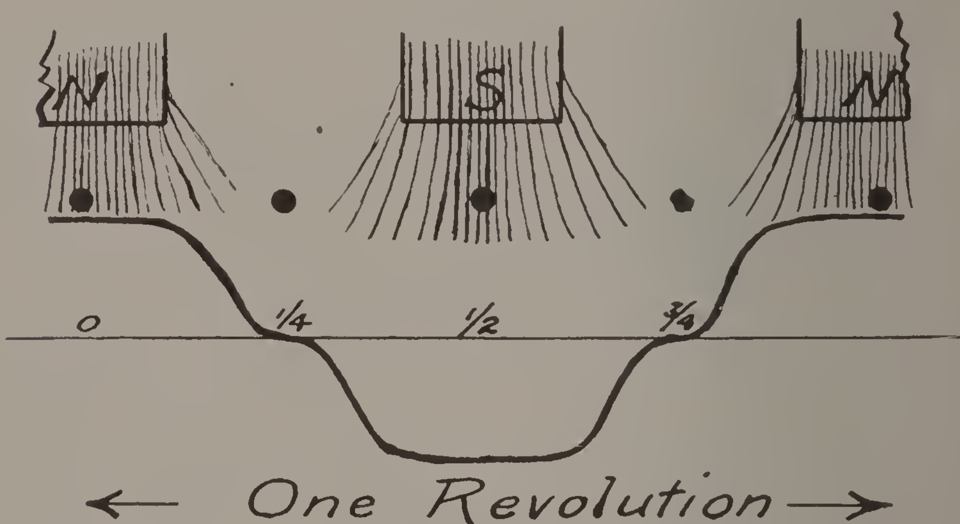


Fig. 182. — Wave of E.M.F., Produced by a Single Coil.

current will gradually increase until the loop has completed a half turn from the position indicated in Fig. 181, when it will be a maximum. As the rotation is continued the current will decrease and again pass through zero as the loop revolves through a point 270° from the starting place in Fig. 181. On the completion of one revolution and the return of the loop to its original position the current will have again reached the maximum value of flow in the direction indicated in figure. The alternating current has thus passed through one complete cycle.

Considering only the top side of the loop, the whole cycle may be graphically illustrated by Fig. 182, the accompanying curve showing corresponding relative values of the electromotive force induced or the current flowing. The small circles indicate the various positions of the conductor with respect to the magnetic poles.

If instead of having one turn the loop should have several turns distributed over a considerable portion of the circumference of the circle in which it revolves, we would have conditions which would give a more gradual change to the direction of flow of the current. This is readily understood when it

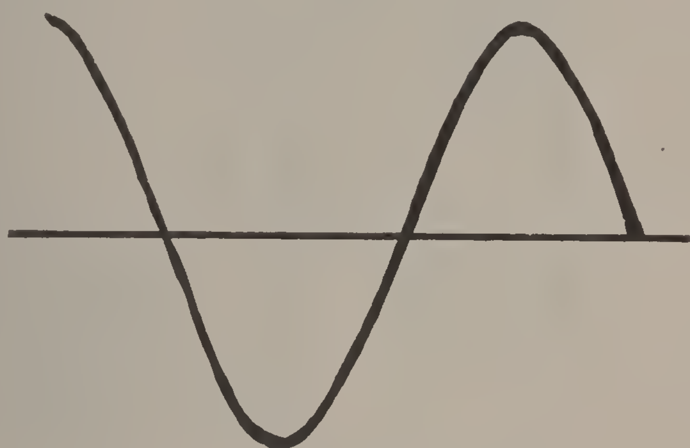


Fig. 183. — Sine Wave.

is considered that all of the conductors would not come under the influence of a pole at once, but one at a time. Under these conditions the values of the E. M. F when plotted would nearly approximate the **sine wave.** A true sine wave is shown in Fig. 183. It is convenient to assume in calculation that the wave is of this form.

Thus far we have been considering the simplest form of alternating current, known as **Single Phase.** This form is used principally for lighting and small motors, while two and three phase is employed for large motors and heavy power, and for long distance transmission.

The terms, **Single, Two** or **Three Phase,** mean that the machine in question (motor, generator, or transformer, as the case may be) has one, two, or three separate and distinct windings.

Several questions naturally arise in your mind:

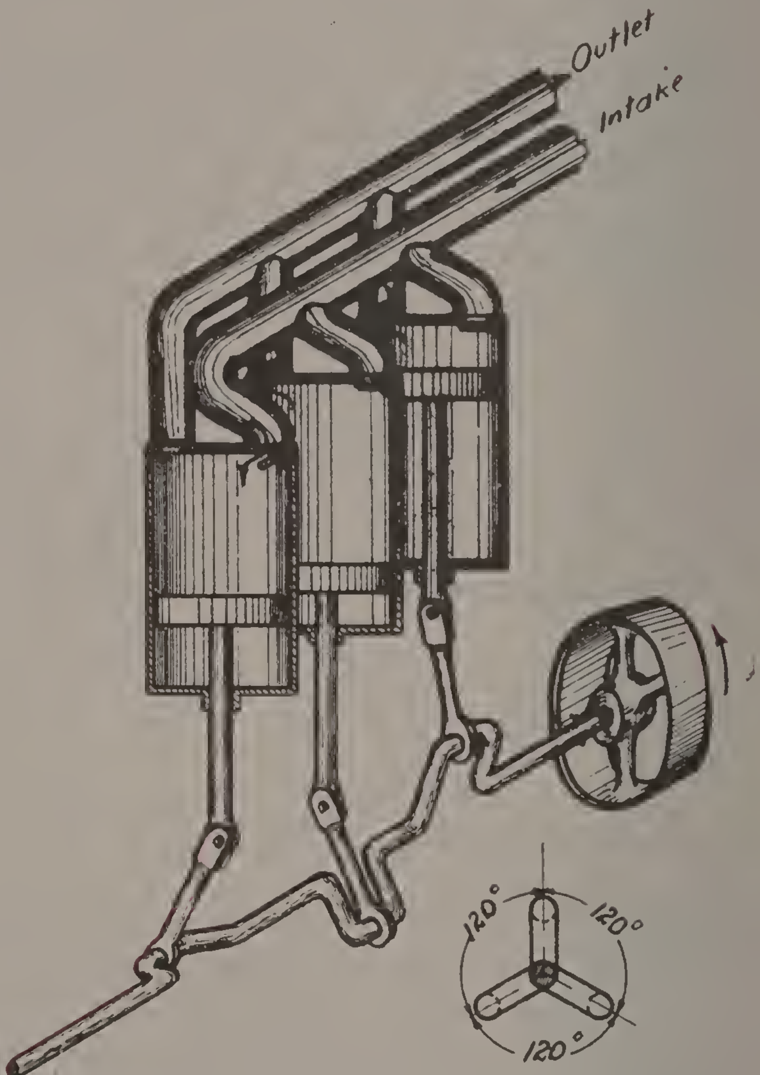


FIG. 184. — THREE-CYLINDER PUMP. ANALOGY OF A THREE-PHASE GENERATOR.

Why are two or more windings better than one, if the same amount of wire is used? How are the phases connected, and what relation do they have to each other? When is single phase used in preference to three phase, or three phase instead of single phase, and why? All of these questions will

be discussed later, but at present we must learn the nature of polyphase currents; that is, currents of more than one phase. In doing so we shall find at least a partial answer to these questions.

We will first draw an analogy between three-phase alternating current and a pump with three cylinders. You are familiar with the gushy, pulsating operation of a single cylinder pump. If three cylinders were so arranged that the pistons were driven by cranks on the same shaft, spaced 120° apart or each one-third of a revolution from the other, the three strokes would come one after the other in regular succession, and result in a more even and much steadier flow from the outlet.

It looks reasonable, and as a matter of fact it is true, that the power obtained from a single phase winding is not steady, but pulsates, becoming zero every time the current or voltage wave passes through zero. To be sure, the current alternates so rapidly that any motor driven by it would not stop during the interval of no power, and the higher the frequency the less noticeable would be the effect of this short interval. But for large, expensive machines it is better to avoid any such jerky, vibratory action, if possible.

As in the case of the three-cylinder pump, if three windings are so arranged in the armature of an alternator that the currents generated by them come to their maximum value 120° or one-third of a cycle apart, one after the other in regular succession, the source of power is more steady and constant.

In Fig. 185 are shown the initial position of the armature coil of phase A, and the curve of E.M.F. produced by the coil as it rotates. It will be noted that the winding is shown directly under the center of the pole, where it will cut the greatest number of lines of force. Therefore, the current generated will be a maximum at this point in the revolution.

In the diagrams, OA and OB represent positive and negative values of the current, while points along the line OX indicate the position of the armature coil, or rather the amount it has been rotated from the initial position shown.

Figs. 186 and 187 show the initial positions and the E.M.F. curves produced by the coils of phases B and C respectively. It will be noticed that the coils are shown in positions 120° from each other, and that phase B will reach its maximum 120° or one-third of a revolution later than A, and C

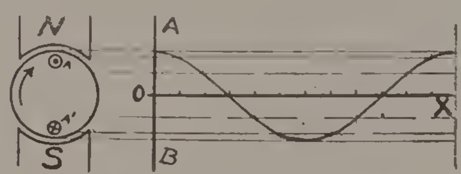


FIG. 185. — PHASE A.

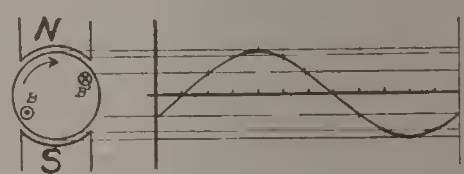


FIG. 186. — PHASE B.

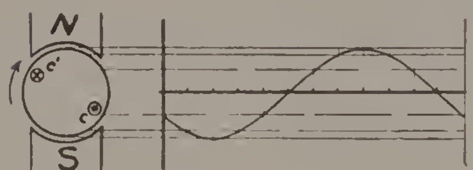


FIG. 187. — PHASE C.

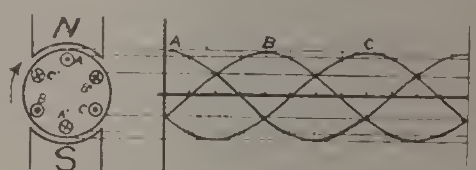


FIG. 188. — E.M.F. CURVES OF A THREE-PHASE GENERATOR.

120° later than B, or one-third revolution before A reaches its second maximum.

Fig. 188 represents the three coils on the same armature, and their curves all drawn on the same diagram. This diagram shows that some phase of the machine is generating an E.M.F. in the positive direction all the time. It can be proved that the total power, which is the sum of the power outputs of all three phases, does not pulsate, but is constant at all parts of the cycle.

The currents from each phase of a three-phase generator might be conducted away by a separate pair of wires, making six wires in all; but in practice

it is unnecessary to use more than three wires. The reason for this may be understood by referring again to Fig. 188. The curves may be considered to represent current instead of E.M.F., as usually the current wave has nearly the same form as that of E.M.F. If a vertical line be drawn through the curves at any point, it will be seen that the sum of the distances to the curves above, along this line, from the zero line (OX), is always equal to the sum of the distances to the curves below the line OX. That is, the current from one phase flowing out along

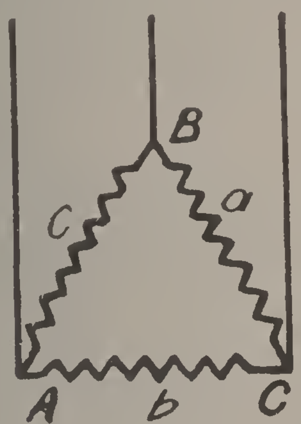


FIG. 189A.

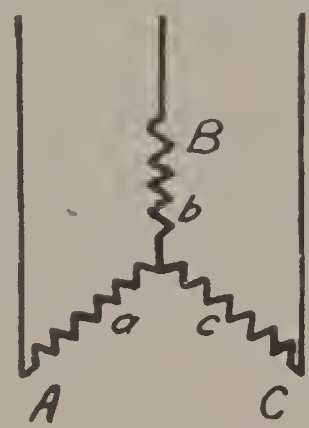


FIG. 189B.

DELTA (Δ) AND STAR OR Y-CONNECTIONS FOR THREE-PHASE CIRCUITS.

one wire returns in the form of the currents from the other two phases, which are flowing in toward the generator along the other two wires.

That it may do this, evidently the three windings must be connected together in some way, both at the generator and at the motors or other apparatus where the electric energy is to be used. There are two methods of making these connections, as illustrated in Figs. 189A and 189B. In Fig. 189A, the phases are said to be **Delta** or Δ-connected, from the resemblance of the diagram to the Greek letter Δ, and in Fig. 189B they are **Star** or **Y**-connected.

In the Δ-connected form, the voltage between the line wires is the same as that generated in each

phase winding, but the current in each wire is that which flows through the two phase windings that are connected to that wire. This does not mean that the amount of current in the wire A, for example, is twice as much as that in the winding b or c. To see why this is not the case, let us refer to Fig. 190. Curve b is the current in the winding b of Fig. 189A, and curve c is that in the c winding, which comes to a maximum 120° later. As the currents from both b and c flow in the wire A, the curve A, which represents the sum of the currents

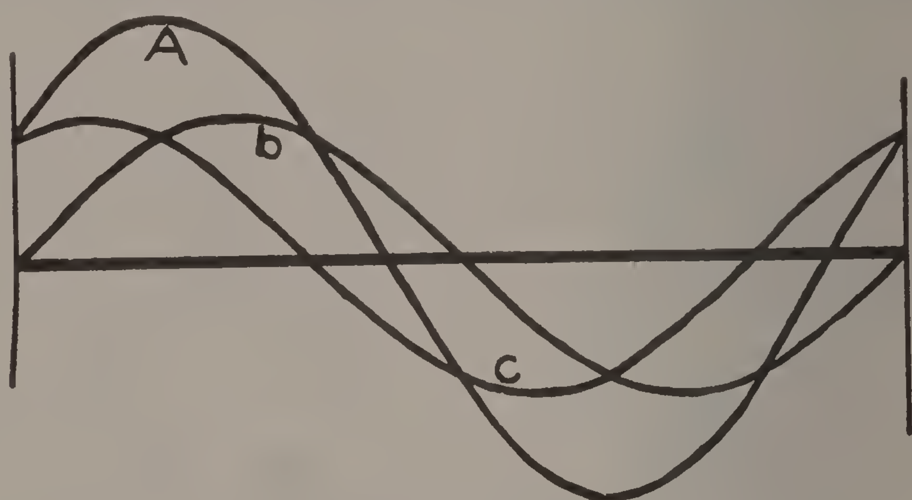


FIG. 190.

b and c at each instant, will represent the current in wire A. You will note that while this current is greater than either b or c, it is not twice as great. As a matter of calculation, it is equal to the current in b times the square root of three ($\sqrt{3}$) or 1.732.

In the Y-connected circuit, on the other hand, evidently the current in wire A is the same that flows in phase a. But the voltage between the wires A and C at each instant is the sum of those generated in phases a and c. Fig. 190 may be considered to represent these voltages in this case just as they represent currents in the case of Δ connections. Therefore, the voltage between wires is that of each phase multiplied by $\sqrt{3}$.

Two-phase systems are in some respects simpler and easier to understand than three-phase, but there are many disadvantages compared with three-phase. One is that four wires must be used instead of three, except at a great disadvantage in the voltage regulation. While there are many two-phase systems in existence, the tendency is toward three-phase systems for power, and for long distance transmission of current for lighting purposes. In some systems using large synchronous motors or rotary converters, 6 and even 12-phase is used; but of late years the best practice has eliminated these complicated windings, and now the tendency is toward an almost universal use of three-phase for large power.

Examine an ordinary incandescent lamp socket and you will note that there are but two connections. Evidently only one phase can be used for lighting. For this reason single-phase current is necessary for supplying lights, but they are often connected to a three-phase system in such a manner that one-third of a given group of lights is supplied from each of the three phases. To accomplish this, one-third is connected between wires A and B, one-third between B and C, and one-third between A and C. It is well to have the load balanced as nearly as possible between the phases, as the regulation of voltage is poor if one phase has considerably more load than another.

In recent years alternating current has been tried quite extensively to supply power for electric railways. On account of the difficulty of using more than one trolley wire or extra rail, it is necessary to use single-phase current for such purposes.

Alternating current generators are usually termed **Alternators,** to distinguish them from direct current generators. As an A.C. machine does not need a revolving commutator, alternators are usually built with the armature in the frame of the

machine, the field magnets forming the rotating element. This makes it necessary to pass only a comparatively small current, to excite the field, through the brushes and sliding contacts, which are always a source of more or less trouble when carrying large currents. A revolving field alternator is illustrated in Figs. 116, 117 and 118.

Looking back over this chapter, we see that:

1. Alternating-current generators and motors are mechanically much simpler than those for direct current.

2. The characteristics and behavior of alternating current is much more complex to calculate.

3. The current alternates in the form of waves, very nearly like the so-called sine wave.

4. Alternating-current systems are Single-Phase, or Polyphase. Polyphase systems generally used are Three-Phase, or Two-Phase. Six, or even Twelve-Phase, is sometimes used.

5. The power delivered by a polyphase generator does not pulsate.

6. Three wires are used instead of six to carry three-phase current. The three phases may be either Δ or **Y**-connected.

7. Single-Phase is used for lights and small motors, and for alternating current railway systems. Polyphase, and usually, in recent years, Three-Phase, is used for large power and long distance transmission.

CHAPTER XXII

TRANSFORMERS

Development — Constant Potential Type — Simple Alternating Current Transmission Line and Explanation Why and How Alternating Current can be Transformed — Reasons for Use of Alternating Current for Long Distance Transmission Work — Constant Current Transformers.

Electrically speaking a transformer is a piece of apparatus for changing the voltage of an alternating current circuit. Essentially a transformer consists of two coils of wire or other electric conductor surrounding a core of iron or other magnetic material. Through one of these coils an alternating current is caused to flow; this is called the primary coil or simply the primary. From the other coil, current may be supplied for lighting or other purposes; this is called the secondary coil or simply the secondary.

A simple transformer is illustrated in Fig. 191. If a current is caused to flow in the primary, magnetic flux will be set up in the iron core in a certain direction. Now we cannot conceive of these magnetic lines circulating around the iron without being cut or interlinking with the turns of the secondary coil. This induces an E.M.F. in the secondary and if the ends of the coil are electrically connected a current will flow. If the primary circuit is opened and current ceases to flow the magnetomotive force will be withdrawn and the magnetic flux will cease to exist in the core. Again we cannot conceive of this magnetic flux being withdrawn without causing a change in the number of interlinkages with the

secondary turns. This will again set up an E.M.F. in the secondary but in the *opposite direction* from the first case. Now let us suppose a current is caused to flow in the primary in the opposite direction to the original, a flux will be set up in the core in the opposite direction, inducing an E.M.F. in the secondary in the same direction as when the first magnetic flux was *removed*. As the current in the primary again dies down to zero, this second magnetic flux ceases to exist, and an E.M.F. will be induced in the secondary in the same direction as when the first magnetic flux was set up in the core. We may now consider the transformer to have passed

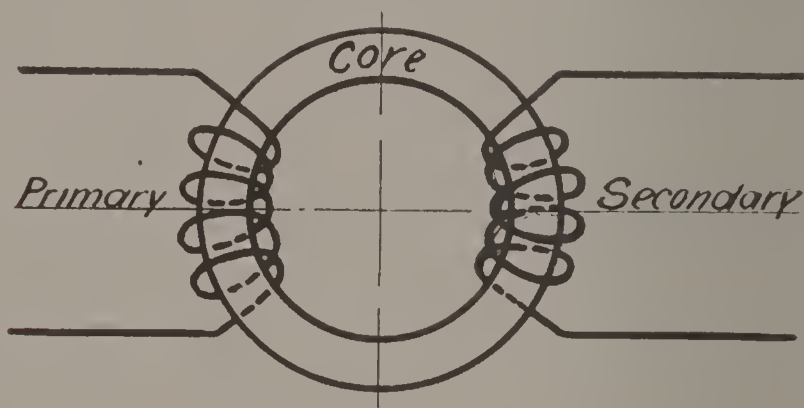


Fig. 191. — A Simple Transformer.

through one complete cycle. If the primary is connected to an alternating current source of supply, the reversals of the alternating-current will cause similar reversals in the magnetic flux, inducing an alternating E.M.F. in the secondary. With the continuous changing in value of the alternating-current, there is a corresponding variation in the amount of flux set up by the primary and interlinking with the secondary. And it is upon this never-ceasing variation in the number of interlinkages that the action of a transformer depends. If connected with a direct-current circuit, there would be a voltage induced momentarily in the secondary as the core flux is rising to its ultimate

value. As soon as this ultimate constant value is reached the number of secondary interlinkages becomes constant and the induced voltage becomes zero. Thus we see a transformer of this kind is not applicable to direct-current. Rotary converters or motor generator sets (sometimes called rotary transformers) must be used for changing the pressures of direct-current circuits and even with these more or less complicated devices the range of available pressures is limited.

To prevent eddy currents, large core losses and excessive heating, transformer cores are built of

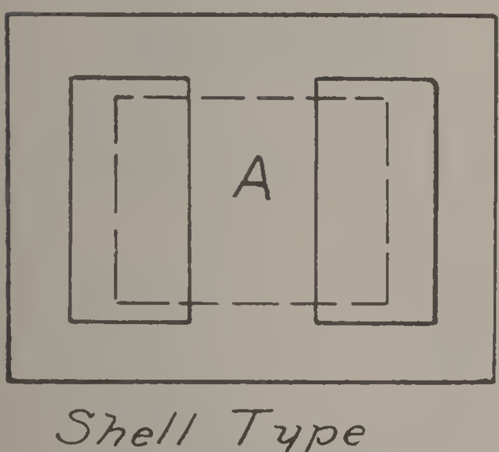


Fig. 192.

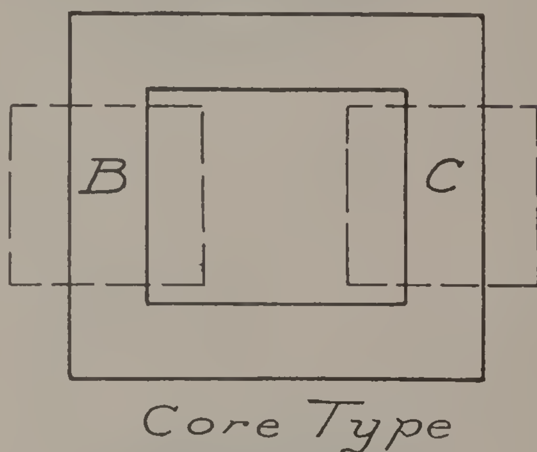


Fig. 193.

laminations. There are two general forms of transformer cores, known as the core type and shell type (See illustrations).

Fig. 194 shows transformer made by Westinghouse Electric and Manufacturing Company in smaller sizes and suitable for pole suspension. The corrugated form of case or box used increases the radiating surface and allows the transformer to operate at a lower temperature. Also by this construction a stronger case can be made with a given amount of iron. The interior view of a Moloney core type transformer is shown in Fig. 195, while the interior of the large shell type transformer made by

the Allis-Chalmers Company is shown in Figs. 196 and 197.

FIG. 194.—WESTINGHOUSE TRANSFORMER IN CORRUGATED CASE.

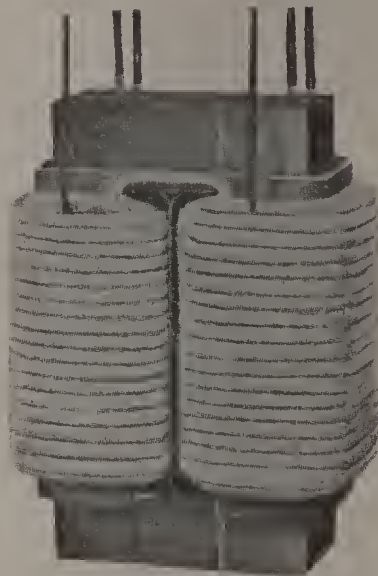


FIG. 195.—A MOLONEY CORE TYPE TRANSFORMER.

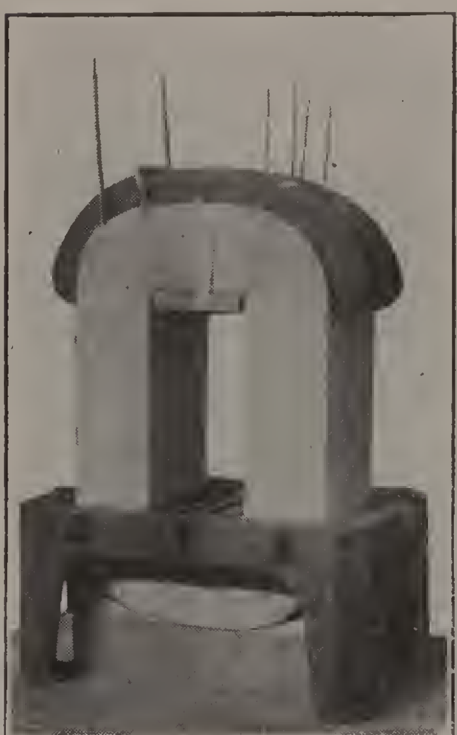


FIG. 196.—WINDINGS.

FIG. 197.—CORE AND COILS.

SHELL-TYPE TRANSFORMER, BUILT BY ALLIS-CHALMERS CO.

Fig. 198 illustrates the core and coils of a transformer put on the market by the Western Electric Company. In place of core type they have adopted as their standard of production the cruciform core, having four magnetic circuits of equal reluctance. The central leg of the core is covered with fibrous insulation and tape to protect the windings from

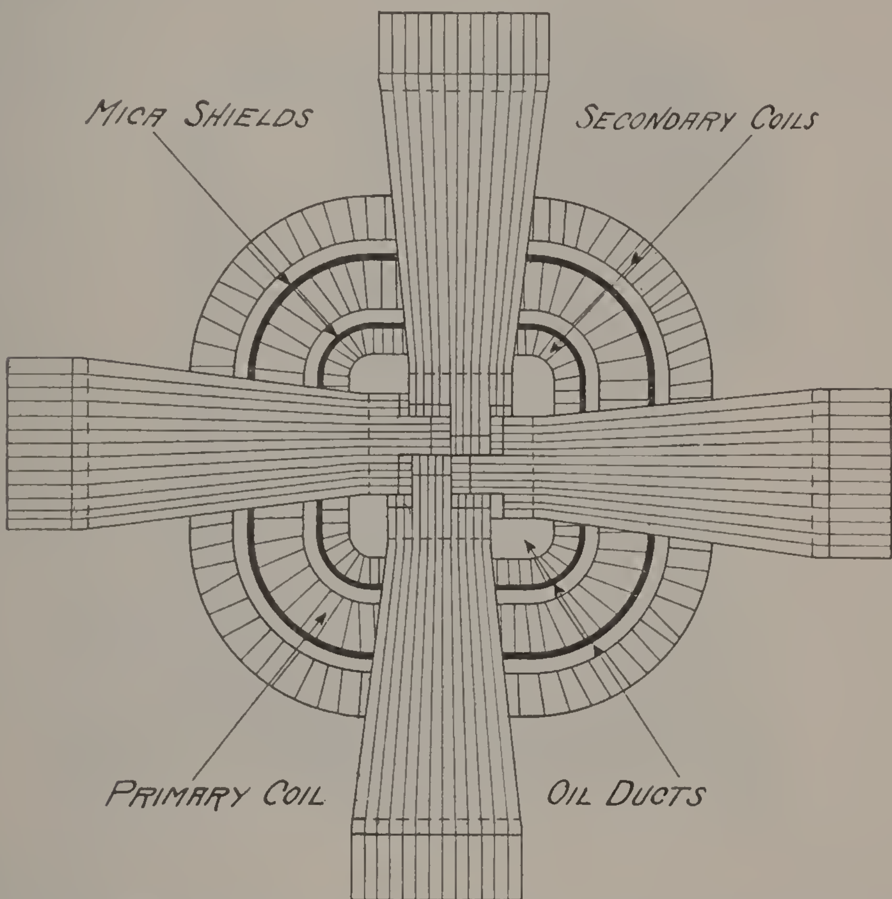


FIG. 198. — END VIEW OF CORE AND COILS, "HAWTHORNE" TYPE T TRANSFORMER. WESTERN ELECTRIC CO.

chafing on the rough edges of the laminations, and to prevent grounds.

The winding machines are similar to lathes. In the smaller sizes the central leg of core is itself placed in the winding machine and the secondary and primary coils wound directly on top of the fibre and tape insulation, mica shields being placed so as to prevent any electrical connection or short circuit

between the primary and secondary windings. Fig. 198 shows a larger size, in which the coils are wound on forms and placed on the core, the secondary being divided into two coils, one placed each side of the primary.

After the winding is completed the outside portions of the four magnetic circuits are put into

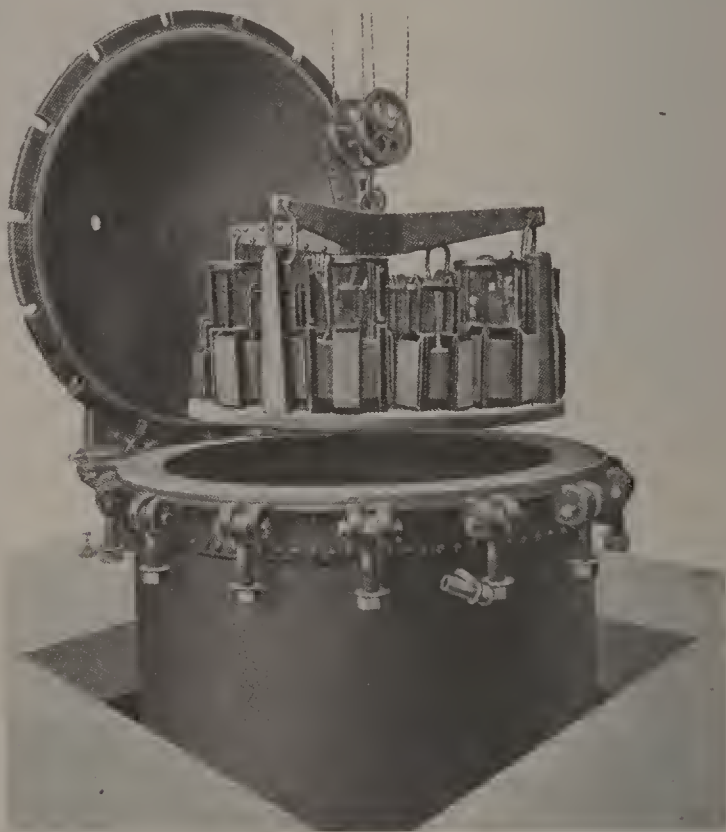


FIG. 199.—"HAWTHORNE" TYPE T TRANSFORMER COILS AND CORES, ENTERING THE INSULATING COMPOUND IMPREGNATING TANK. WESTERN ELECTRIC CO.

place and the complete core, coils and connection board are put through a vacuum drying and compound filling treatment which is worthy of mention. The fibrous insulation used in the Western Electric Company transformer is sufficient to stand high potential tests for all ordinary conditions of safety. When the core, coils and terminal-boards completely assembled are placed in this compound tank,

shown in the illustration, they are first subjected to a very thorough baking, until all moisture is expelled from even the innermost parts of the windings. The coils are then sealed up by the compound, which is forced in under pressure while in a molten condition. Upon solidification of this compound the coils become moisture proof and are also given

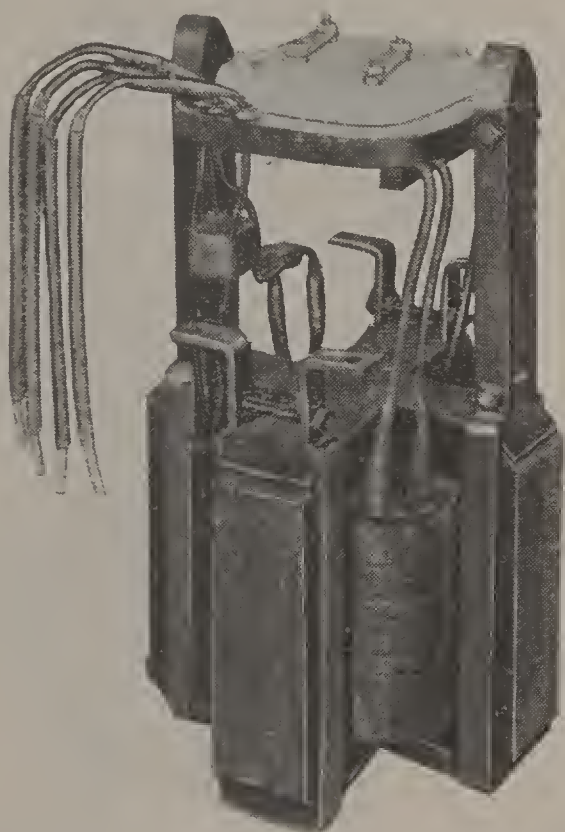


FIG. 200.—ASSEMBLED VIEW OF CORE, COILS, LEADS AND TERMINAL BOARD OF "HAWTHORNE" TYPE T TRANSFORMER.

additional mechanical stability and protection from chafing. This tendency to chafe is due to vibration from the alternating current and to the alternate expansion and contraction taking place as the transformer heats and cools. Also it is claimed that this compound, being a good conductor of heat, insures lower operating temperature than can be obtained without its use.

Figs. 200 and 201 show views of Western Electric transformer before and after coils have been placed in case.

The Westinghouse Electric & Manufacturing Company have a modified shell type transformer with a core shaped very similar to the cruciform in the Western Electric Company type.

Fig. 205 shows the assembled coils for two different Westinghouse transformers, bringing out

Fig. 201.—External View, "Hawthorne" Type T Transformer.

very clearly the method used to separate the coils and to provide ventilating ducts through which the oil circulates. This is a very important feature as it offers a means for cooling the inside of the coils and prevents excessive temperature near the core while the outside might apparently be cool.

As oil is a much better conductor of heat than air, the operating temperature of the transformer will be reduced if the coils are immersed in oil. An oil commonly used for this purpose is known as

FIG. 202.—WESTINGHOUSE TYPE S TRANSFORMER.

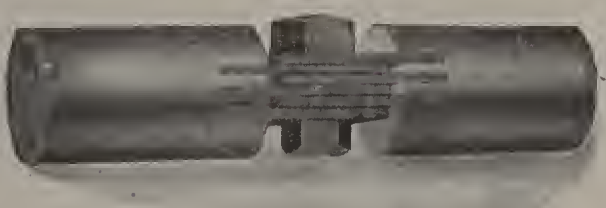


FIG. 203.—LEAF CONNECTOR USED ON LARGE WESTINGHOUSE TRANSFORMERS.

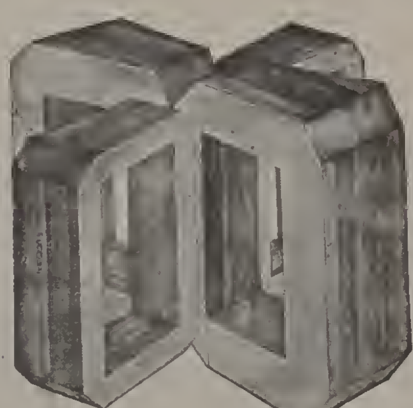


FIG. 204.—MAGNETIC CIRCUIT OF WESTINGHOUSE TYPE S TRANSFORMER.

"Transil Oil," No. 6 and No. 8 being two grades in commercial use. It is obtained by fractional distillation of petroleum, unmixed with any other substance and without subsequent chemical treatment, and rather than having any injurious effect upon the insulation, its influence should be preservative, making the insulation soft and pliable, increasing the insulating value of the transformer and pre-

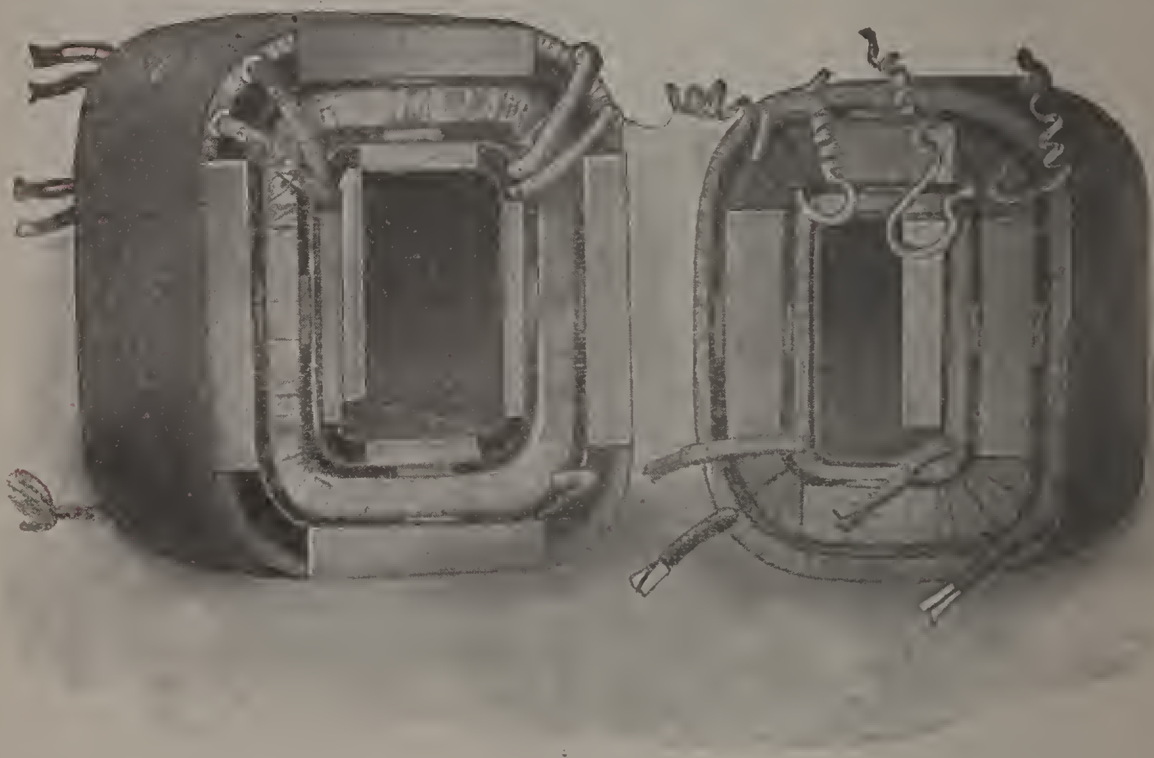


Fig. 205.—Assembled Coils of Westinghouse Type S Transformers, Showing Ventilating Ducts.

venting oxidization by the air. It should have a high flash point, or in other words, the temperature at which it will ignite should be high, and also its freezing point should be reasonably low, so as not to freeze in winter.

Although counteracted to a certain extent by the heat from the windings, transformers are frequently located out of doors and subjected to severe cold. The freezing point of No. 6 transil oil is 12

degrees below zero (Centigrade) and for No. 8 it is 18 degrees below zero (Centigrade).

The ratio of the primary voltage to the secondary voltage is called the ratio of transformation, or simply its ratio. Instead of quoting the actual voltages of transformers it is customary to speak of the ratios as so many to 1. That is a transformer

FIG. 206. — ALLIS-CHALMERS OIL-FILLED, WATER-COOLED TRANSFORMER.

A coiled pipe is placed in the oil. Cold water flows through the pipe and keeps the operating temperature at a low point.

ratio 2,000 volts to 100 volts would be called ratio 20 to 1. Now let us suppose we have a transformer with a ratio 1 to 1. There the primary and secondary voltages would be the same and the primary current would equal the secondary current plus a small amount of extra current, which is commonly known as the exciting current, and still another small amount of current that supplies the energy lost in

the apparatus. For the present we will disregard the losses of the transformer.

The alternating flux in the core not only induces an alternating E.M.F. in the secondary but also induces an alternating E.M.F. in the primary, which is always in opposition to the impressed E.M.F. The magnetizing current producing the magnetic flux increases until this induced or back E.M.F. is nearly equal to the impressed E.M.F. This back E.M.F. prevents an excessive current from flowing in the primary, the resistance of which is very low. Now if the secondary supplies current to a load, say of lamps, this secondary current will tend to set up a magnetic flux in the core in the opposite direction to that set up by the primary current. This at once causes the flux set up by the primary to decrease, causing the induced or back voltage in the primary winding to decrease, which will allow a greater primary current to flow and consequently tend to bring the magnetic flux up to its first value. Thus as the load or amount of current taken from the secondary is increased, the primary automatically takes an increased amount of current from the source of supply.

The **advantages** of the **transformer** are synonymous with the advantages of the alternating current systems; that is, the economy in distribution and long-distance transmission of power.

With the exception of the special cases with ring-armature construction, it is not practicable to build a direct-current machine for greater than about six or seven hundred volts. At this latter voltage, the expense of transmitting power any great distance would be prohibitive.

Let us suppose we had to deliver a certain amount of water per hour over a distance of one mile. We could deliver this water through a large pipe at low pressure or through a small pipe at high pressure. In the same way we can deliver a certain

amount of electrical energy at low pressure over large conductors or the same amount at high pressure over comparatively small conductors. But for lighting and many power applications high voltage is not only unsatisfactory but dangerous, and here is where alternating current through the use of the transformer finds its greatest field. The electrical energy may be generated at the central station at a certain pressure or voltage, and by the use of the transformer this voltage may be "stepped up" to a much higher value and the energy transmitted over small wires to outlying districts or even other cities miles distant. At the receiving end it may be "stepped down" with transformers to voltages best adapted to the purpose for which it is to be used. The transformer has no moving parts and requires little attention, being frequently installed in isolated stations or on poles which are also used to support the wires of the transmission line.

A similar transformation and transmission of energy by means of direct-current would require an electrical generator driven by an electric motor, commonly known as a motor-generator set, to step the voltage up at the central station and another motor-generator set to step the voltage down at the receiving end of the line. These sets would not only cost several times as much as the transformers but would require constant attention and their reliability would be much less than that of the transformer. Furthermore, it is a simple matter to build a transformer to operate on voltages that are unattainable with direct-current apparatus. So aside from the fact that first cost, maintenance, and reliability are all in favor of alternating-current machinery for transmission of power to any appreciable distance, in most cases the voltage suitable for the most economical line construction would be unattainable with direct-current machinery.

If a certain amount of water is being delivered

through a pipe, say to a water-motor at high pressure, a part of that pressure will be used in forcing the water through the pipe, and the more water the motor takes the more pressure will be used up in forcing the water through the pipe. Similarly, when electrical energy is being transmitted over a line a certain amount of pressure or voltage is used up in forcing the current over the wires. This is called the line drop and also varies directly as the load or the amount of current taken by the receiving end. Probably few users of electric lights realize that a small variation in their voltage seriously affects both the amount of light and the length of the life of their lamps.

As the line drop varies with the changes in load so the voltage at the receiving end depends on load. If energy was transmitted from the central station to outlying districts at the ordinary voltage (110) used for commercial lighting, it would be necessary to use an enormous amount of copper in order to keep this variation of voltage, due to variation in load, within satisfactory limits. Here again the transformer finds its field. By stepping the voltage up at the station and down at the receiving end the same energy can be transmitted with a comparatively small amount of copper, and a small line drop which will be a still smaller percentage drop, due to the higher transmission voltage, and with a resulting decrease in variation in voltage at the receiving end. For instance, suppose it is desired to furnish a customer, a mile distant, with energy at 110 volts for 40 carbon incandescent lamps with a variation due to line drop of 2 volts. This would mean a transmission of about 20 amperes, which would mean a total line resistance of $\frac{1}{10}$ ohm if the transmission was made at 110 volts.

Now let us suppose the transmission was made at 2,200 volts. This would mean that a line loss of 40 volts would be permissible. Also the current

necessary to supply the same amount of energy would be $\frac{1}{20}$ of 20 or 1 ampere. For a line drop of 40 volts a line of 40 ohms resistance would be satisfactory. As this is 400 times as high as the resistance of the line necessary to transmit the energy at 110 volts, it means that $\frac{1}{400}$ of the copper would be necessary. In other words, the amount of copper

FIG. 207. — A GENERAL ELECTRIC CONSTANT CURRENT TRANSFORMER.

necessary to transmit a certain amount of energy with a certain percentage line drop varies inversely as the square of the voltage.

As commonly made, the core of a **Constant Current Transformer** is of the shell type, and one of the coils is suspended from one end of a rocker arm, which has a counterweight on the other end. This rocker arm is supported on knife-edge bearings,

resting on hardened steel supports, minimizing friction.

The primary coil, commonly the stationary one, is connected to the constant potential source of power. The secondary coil, usually movable, delivers con-

Fig. 208. — A General Electric Constant Current Transformer, with Case Removed.

stant current at varying voltage, and the load generally consists of arc or incandescent lamps, in series.

Fig. 207 shows the external appearance of a constant current transformer as made by the General Electric Company, and Fig. 208, in which the case has been removed, shows the arrangement of the core and coils.

With the transformer in operation, if a part of the load is taken off, or short-circuited, its resistance will be decreased and the current in the secondary will rise, increasing the repulsion between the two coils due to the currents in them. This increased repulsion causes the coils to separate more and a correspondingly larger leakage of the flux from the primary, and the voltage of the secondary is cut down proportionally. Consequently the current falls, and if the transformer is properly adjusted, the current will return to its former, normal value.

If more load is put on, the current in the secondary is cut down, the repulsion between the coils is less and they come closer together. More lines of force from the primary interlink with the secondary, and the current in it, as a result, rises to its former value.

CHAPTER XXIII

RECTIFIERS

Mercury Arc Type — Constant Potential — Constant Current.

It is well known that direct-current arc lamps have higher efficiency and better light distribution than the alternating current lamps, and with the magnetite or metallic flame lamp, for direct-current series circuits, these advantages are even more pronounced, and also there are additional points in its favor, such as a better quality of light and lower maintenance cost.

This is one of the more important instances where direct-current is superior to alternating, while at the same time, due to their many well-known advantages, alternating-current systems of transmission and distribution have been installed in many localities. And in these instances, where only alternating-current is available, it is often desirable and sometimes necessary to have some means of converting the alternating to direct current.

Until recently this conversion was accomplished by motor generators or rotary converters, both of which require large floor space. The former has a rather low full-load efficiency and a very low light-load efficiency, while the latter requires more attention, and should, preferably, be started and operated only by one familiar with rotary converters. Mechanically driven and chemical rectifiers have not proven reliable in the past.

Most of these disadvantages are overcome or eliminated when a mercury arc rectifier is employed.

While it has been on the market a comparatively short time, the mercury arc rectifier has been in-

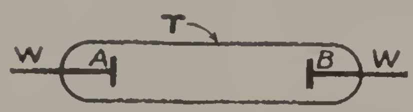


FIG. 209.

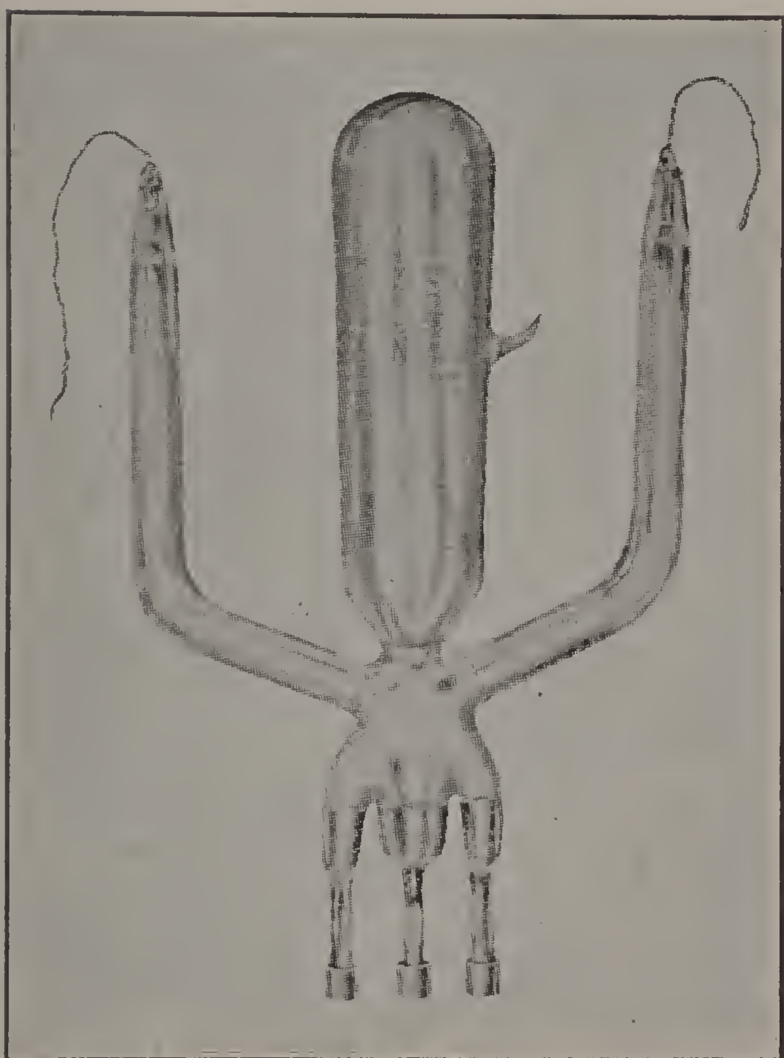


FIG. 210. — GENERAL ELECTRIC CONSTANT CURRENT RECTIFIER TUBE.

stalled in many cities, and has been in service long enough to justify most of the claims of the manufacturers. It requires but little floor space and has

no rotating parts. The first cost is low and the efficiency at both full and light loads is high.

Suppose the air is practically exhausted from a glass vessel, such as *T* in Fig. 209, and which contains mercury vapor. If a low voltage is impressed on the wires *WW*, leading to the electrodes *A* and *B* in the tube, no current will flow, as the vapor will act as a non-conductor. But if this impressed electro-

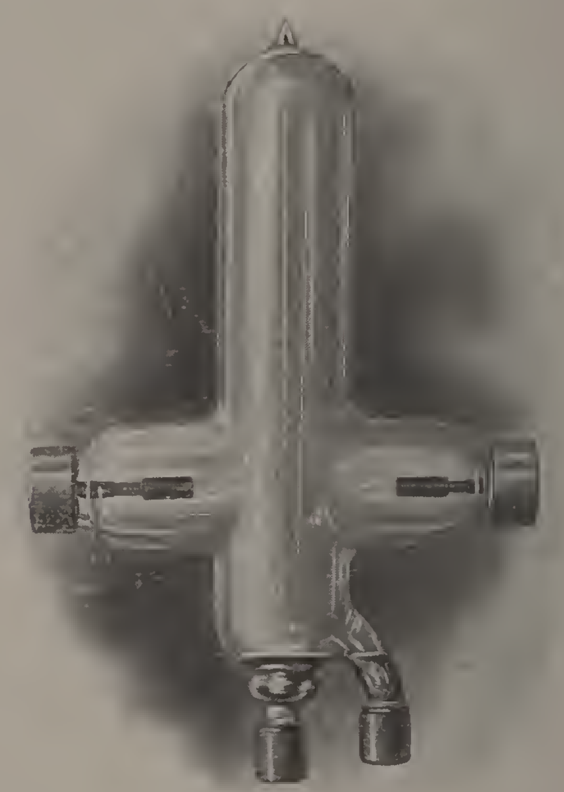


Fig. 211. — Westinghouse Constant Potential Rectifier Bulb.

motive force is increased sufficiently, it will jump across, or arc from one electrode to the other, and in so doing will break down or ionize the mercury vapor so that it will now allow current to flow in one direction, but remains practically a non-conductor to the passage of current in the opposite direction.

The operation of the mercury arc rectifier is based on this principle or property of mercury vapor.

Fig. 210 represents a tube manufactured by the General Electric Company, while Fig. 211 illustrates a Westinghouse bulb. Fig. 212 shows a view of the complete rectifying outfit, as manufactured

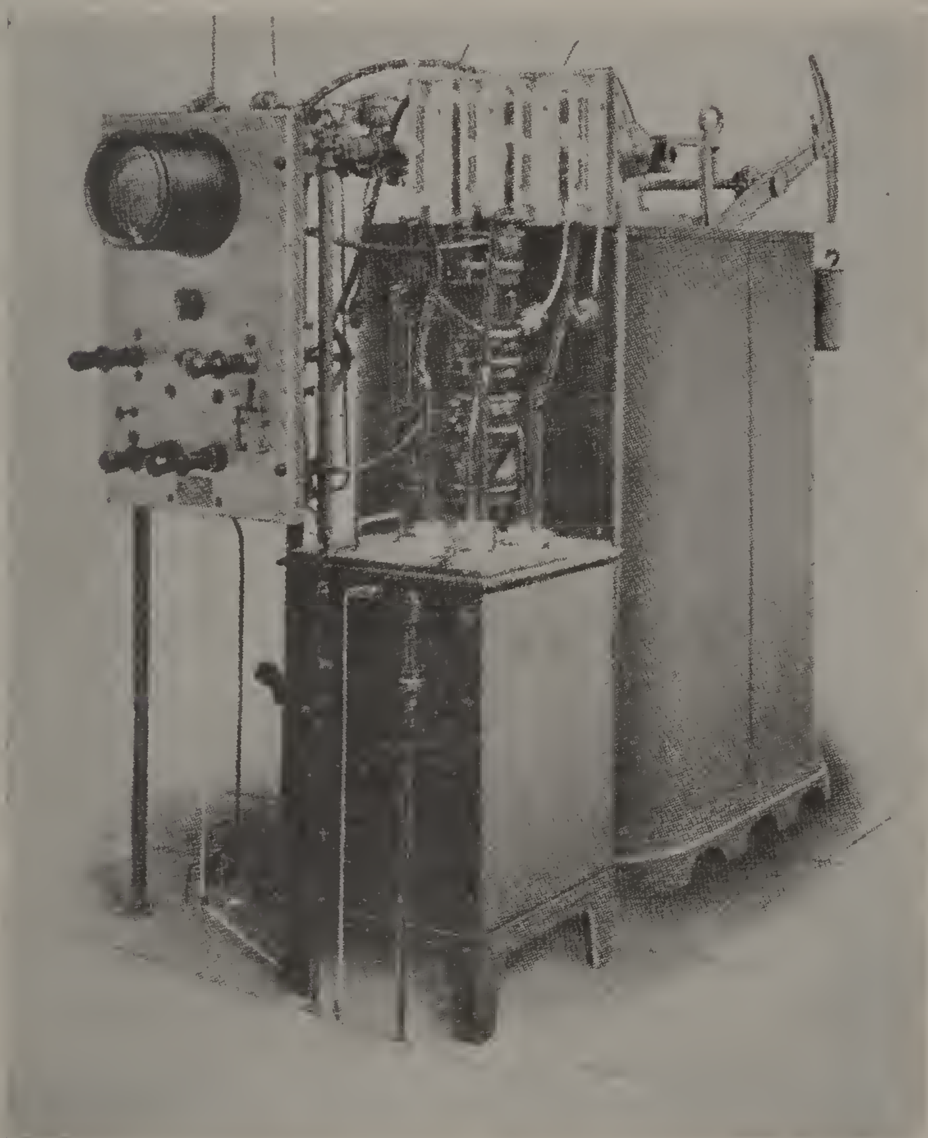


FIG. 212. — SERIES RECTIFIER OUTFIT FOR 50-LIGHT SYSTEM. GENERAL ELECTRIC CO.

by the General Electric Company, and which consists of a constant-current transformer and reactance, an exciting transformer, tube tank and tube, static dischargers and switchboard panel. The constant-current transformer and reactance coil are

contained in one case and air cooled. The tube is supported on a wooden holder and immersed in the water-cooled oil in the tube tank. The static dischargers are employed to protect the tube and other parts of the system from excessive electrical strains.

The operation of the system and the conversion of current can be explained as follows: With reference to Fig. 213, which is a diagram of connections, suppose we begin to consider the constant-current system during a time when the current in

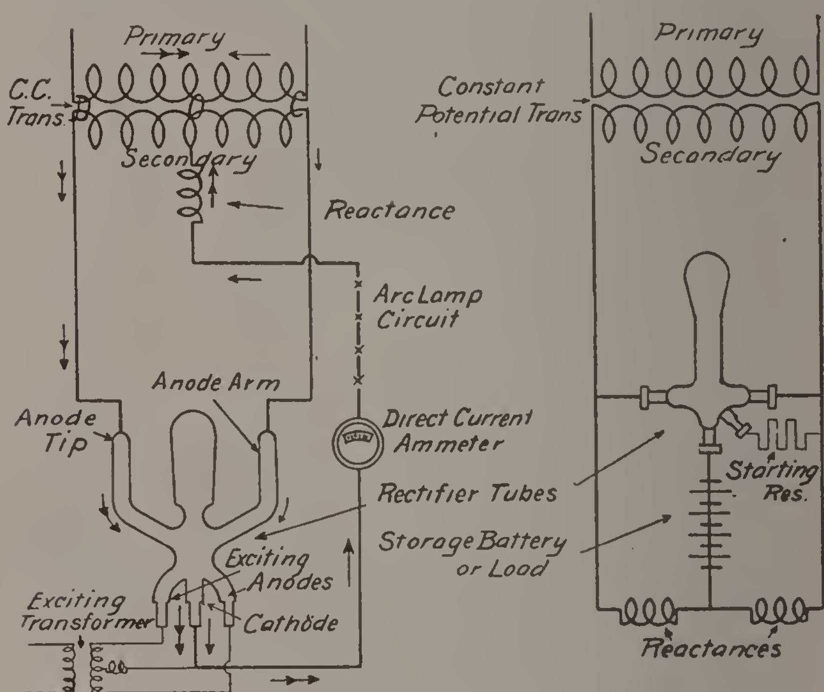


FIG. 213.— DIAGRAMS OF CONSTANT CURRENT AND CONSTANT POTENTIAL RECTIFIERS.

the primary of the constant-current transformer is flowing from C to D, as indicated by the single-headed arrow.

If the vapor in the tube is ionized so that it will allow current to pass from either *anode* to the *cathode*, the section CO of the secondary will cause current to flow through the tube from the right-hand anode to the cathode, through the ammeter, lamps, reactance and back to O. During this time the section OD of the secondary is necessarily idle, as

the vapor in the left-hand part of the tube is a non-conductor in the direction in which OD would tend to make the current flow. (It will be remembered that the flow of current in the secondary of a transformer is opposite in direction to that of the primary during each alternation).

During the next alternation the current in the

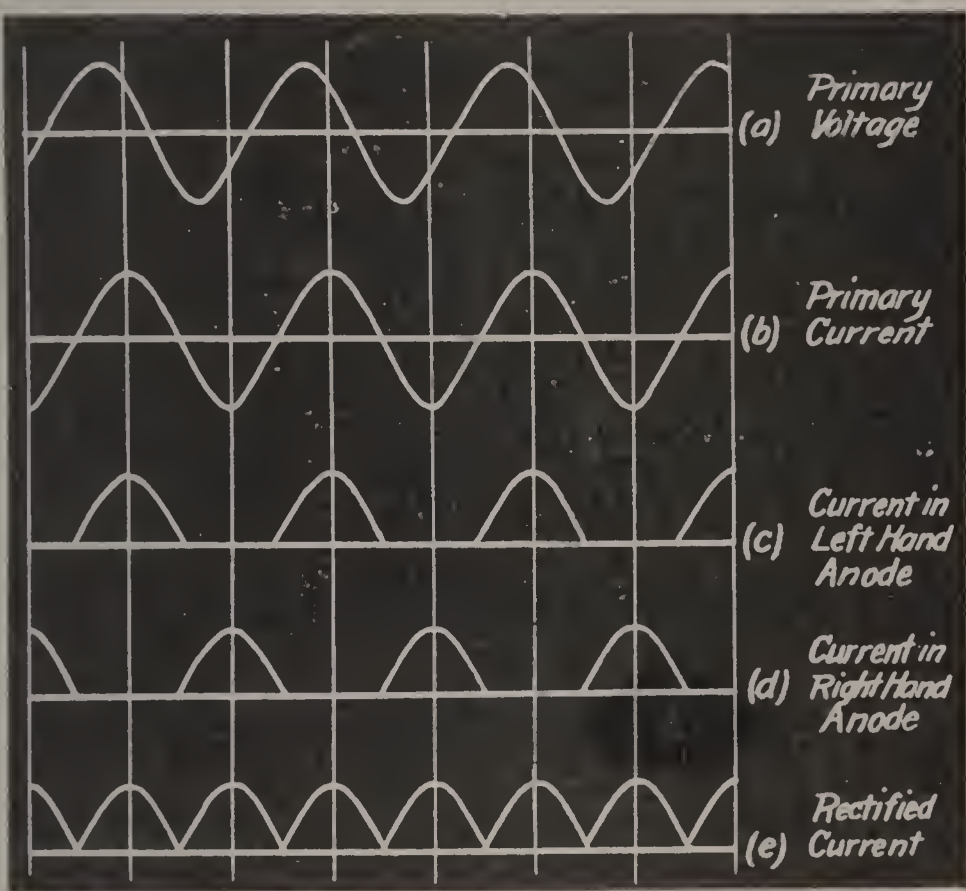


FIG. 214.—WAVE FORM WITHOUT REACTANCE IN THE CIRCUIT.

primary flows from D to C in the direction of the double-headed arrow, which symbol also indicates the direction of the flow of current throughout the circuit controlled by section OD of the secondary, OC now being idle.

In Fig. 214 a and b show the wave form of the primary voltage and current, and if the effect of reactance coil is ignored the wave form of the

current in sections *OC* and *OD* of the secondary are illustrated by *c* and *d*. If these are combined the result will be a unidirectional or rectified current, as represented by *e*.

If such a current as this was used, the rectifier arc would go out every time the current became zero. Thus there is need of some means to maintain or carry over the arc, and this is accomplished by the reactance, which is connected between the

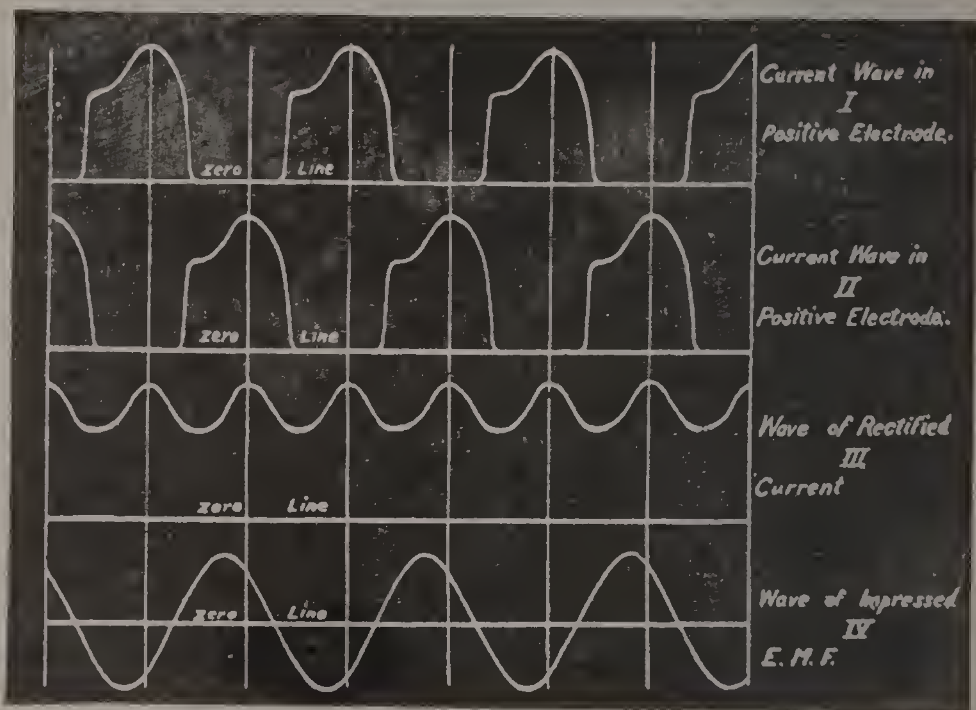


FIG. 215 — WAVE FORM WITH REACTANCE IN THE CIRCUIT.

lamps and the point *O* of the secondary of the constant current transformer.

The effect of the reactance can be likened to a flywheel on an engine. That is, the reactance tends to keep the current at the same value, and if it starts to die away the reactance will tend to sustain or keep it flowing. In other words, the reactance produces an elongation of the current waves in the two anodes, as shown in Fig. 215, I and II. When these two are combined they overlap each other and

the resulting current in the lamps is slightly pulsating, as represented by Fig. 215, III.

In starting a tube or bulb for the first time, the following precautions should be observed. As a preliminary move, with tubes such as shown in Fig. 210, it is a good plan to take the tube and with the mercury wash out around the anodes carefully, being sure that no little dots or particles of mercury are left adhering to the glass near the anode tips, as if not removed, they may cause the tube to be punctured soon after starting up.

Then place the tube in the holder and make the necessary connections. The coils of the constant current transformer are pulled apart and the primary is "plugged on" or connected to the source of power, the lamps being short-circuited meanwhile.

The tube holder is next rocked back and forth through a small angle, and as this is done, the mercury bridges the space between the exciting anodes and the cathode, completing the secondary circuit of the exciting transformer and allowing current to flow. When the mercury runs back and breaks the metallic circuit an arc is formed, ionizing the mercury vapor, as explained above, the only difference being that instead of using high potential to break down the vapor and produce ionization, this is accomplished with a low potential, about 110 volts, by placing the exciting anodes in close proximity to the cathode and by the shaking of the tube, as just explained.

It will be noted that when the tube is shaken the mercury bridges the space between the exciting anodes and the cathode, momentarily short-circuiting the exciting transformer, which is so designed that the current under these conditions is not excessive. The capacity of this transformer is about 100 watts and it can be disconnected from the circuit after set is started up.

CHAPTER XXIV

A. C. MOTORS AND CONVERTERS

Induction Motors — Synchronous Motors — Rotary Converters.

Suppose the pole pieces shown in Fig. 216 were so supported as to allow their being rotated freely. If the coil was stationary the conductors would cut

Fig. 216.

lines as the poles passed by, inducing an E.M.F. which would cause current to flow in the short-circuited coil as indicated in Fig. 217. This current would react on the field and produce a force tending to cause rotation in the direction pointed out. In

other words, the coil would tend to follow the pole pieces. However, no matter how easily rotated, the coil can never revolve at exactly the same speed as the poles, as there would be no lines cut under

Fig. 217.

those conditions, and no induced currents. It must necessarily "slip," or revolve at a slower rate, in order to cut lines, induce current, and produce a reaction. The greater the difference in speeds, the

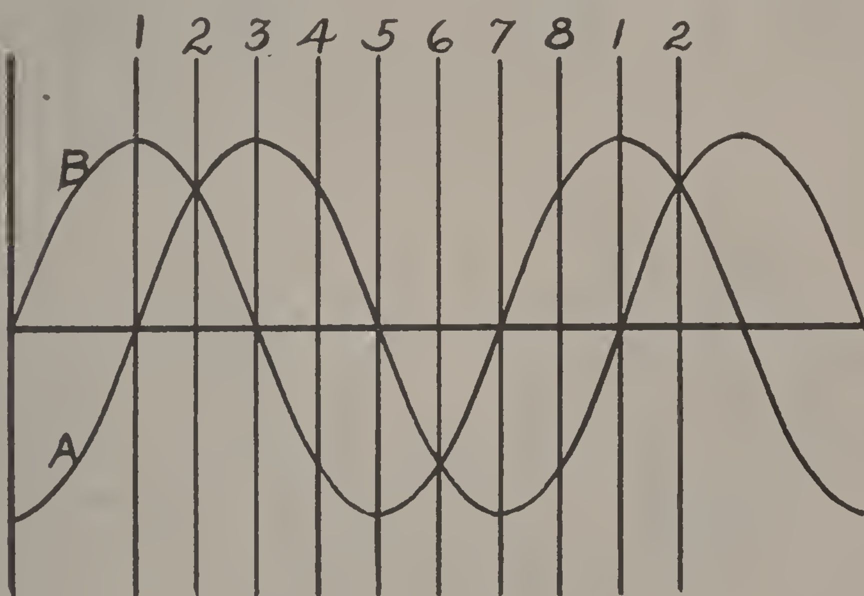


Fig. 218.

more lines are cut, and within certain limits, the greater the turning effort, as the induced currents will be larger and the reaction stronger.

Fig. 218 is a wave diagram of the currents in a two-phase circuit. The time, represented by the

horizontal line, is divided into eight equal periods by the vertical lines 1, 2, 3, 4, 5, 6, 7 and 8.

Suppose *A*, *A* and *B*, *B* (Fig. 219) to be the parallel sides of two rectangular coils at right angles to each other. If coil *A*, *A* is connected to one phase and *B*, *B* to the other of the two-phase source of supply, there will be a peculiar magnetic field produced, that will rotate with the relative changes of magnitude of current in the two phases, although the coils do not move. To trace out the combined magnetic effect of the currents in the two coils, refer to Figs. 219 to 226, which show the resulting magnetic fields when currents have the values and

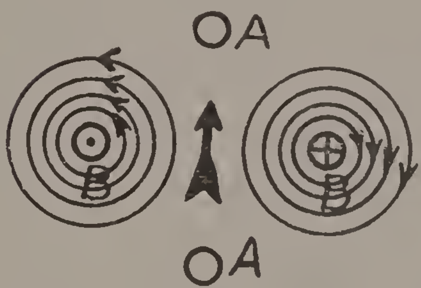


FIG. 219. — CASE 1.

FIG. 220. — CASE 2.

directions given in the wave diagram at the vertical lines 1, 2, 3, etc.

CASE 1. Current in phase *A* is zero, current in phase *B* is a maximum in the positive direction, say 10 amperes. The field would be as shown in Fig. 219, and a compass needle placed in the centre of the two coils would point in the direction shown.

CASE 2. Current in phase *A* gradually increasing in positive direction, current in phase *B* decreasing. Current in two phases of equal values 7.07 amperes. It will be noted that the needle has rotated to a new position.

CASE 3. Current in phase *A* has become a positive maximum of 10 amperes, current in phase

B has become zero. Field produced is due solely to the current in the coil *AA*, and is as shown, with the needle pointing along the lines of force.

Case 4. Current in phase *A* gradually decreasing, value 7.07 amperes; current in phase *B*

Fig. 221.—Case 3.

Fig. 222.—Case 4.

gradually increasing in a negative direction, value 7.07 amperes.

Case 5. Current in phase *A* has become zero, current in phase *B* has become a negative maximum, 10 amperes.

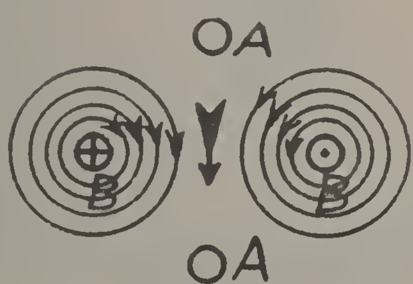


Fig. 223.—Case 5.

Fig. 224.—Case 6.

Case 6. Current in phase *A* increasing in a negative direction, value 7.07 amperes; phase *B* current decreasing, negative value 7.07 amperes.

Case 7. Current in phase *A* negative maximum, 10 amperes; phase *B* has become zero.

CASE 8. Current in phase *A* decreasing, negative value 7.07 amperes; current in phase *B* increasing in the positive direction, value 7.07 amperes.

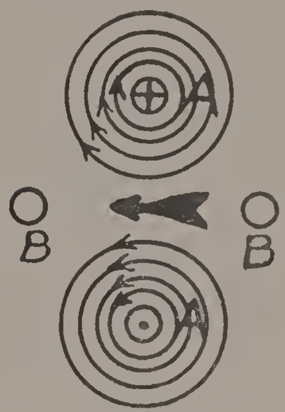


FIG. 225. — CASE 7.

FIG. 226. — CASE 8.

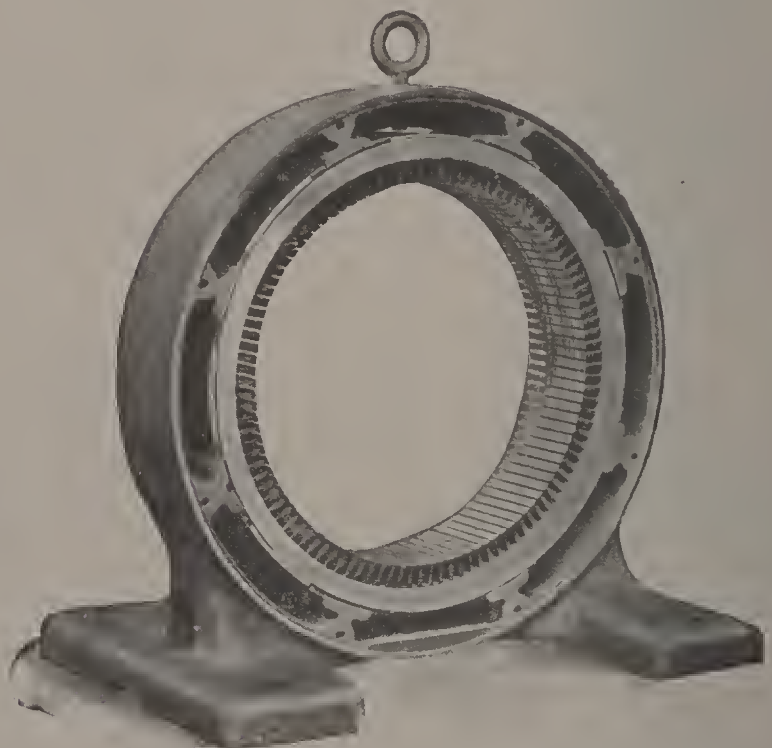


FIG. 227. — STATOR CORE OF WESTINGHOUSE, TYPE CCL, INDUCTION MOTOR.

Thus during one cycle the needle has turned through 360°. We have produced a magnetism which rotates with the changes in current, although

the coils were stationary; and the faster the currents change, or in other words, the higher the

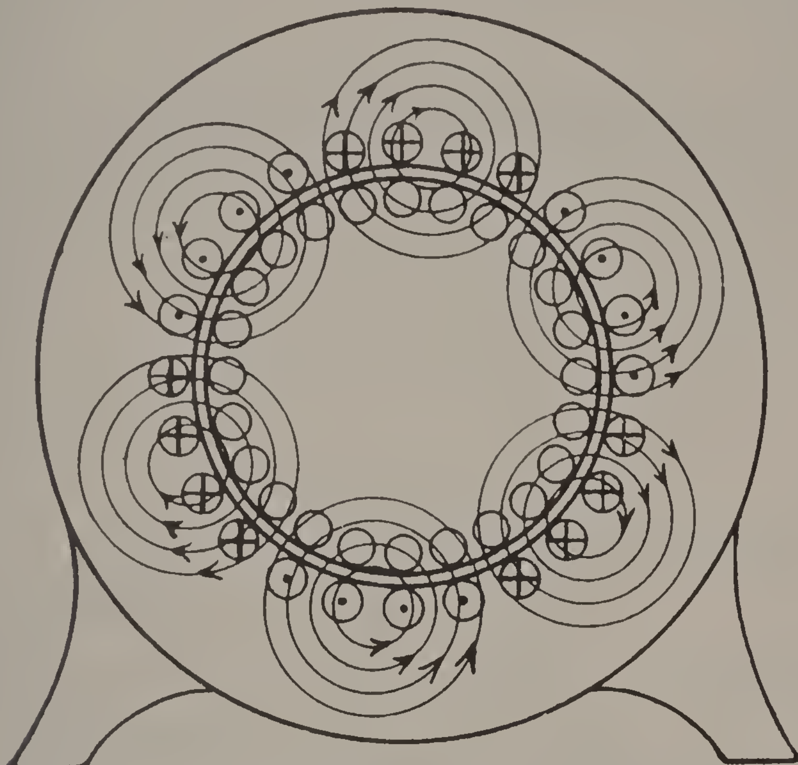


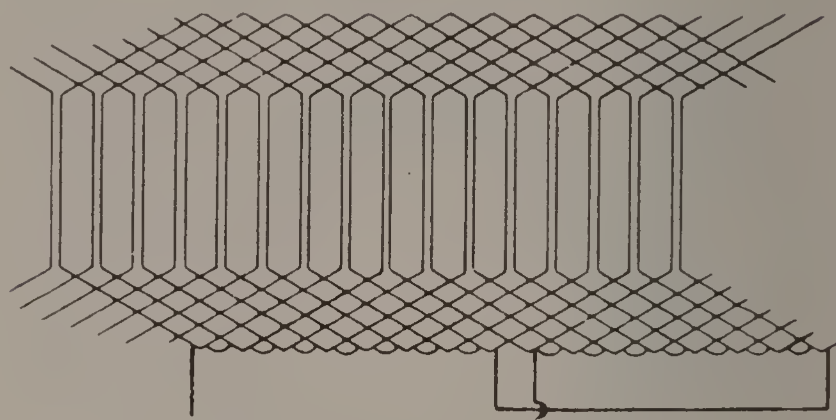
Fig. 228. — Rotating Field in a Six-Pole Induction Motor.

frequency, the faster the rotation of the compass needle. Roughly speaking, this is the idea or principle of the induction motor. The **synchronous speed** of an induction motor is the rate of rotation of the field, usually expressed in R.P.M.

Three-phase currents, with the proper windings, will produce a revolving field even more readily than two-phase, though the action of two phases is easier to follow in studying the principle. The winding may be either one, two, or three-phase, and is placed in the slots of a core built up of laminations as shown in Fig. 227.

The coils may be arranged so that each phase will produce two, four, six, eight, or even more magnetic poles. Fig. 228 shows the magnetic flux in a six-pole motor. A winding diagram showing the connections of a two-pole single-phase induction

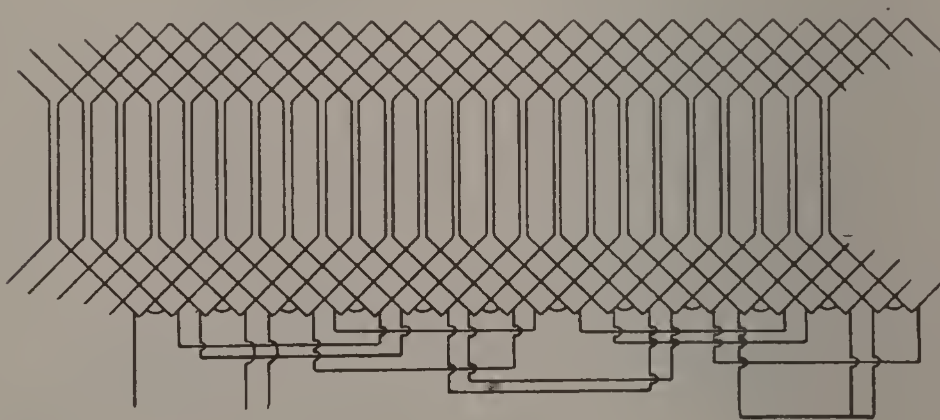
motor is given in Fig. 229, while Fig. 230 illustrates the connections of a four-pole, three-phase, 24-slot winding.



2-Pole, 16-Slot, 87½% Pitch.

Fig. 229. — Winding Diagram for Two-Pole, Single-Phase Induction Motor.

A common form of revolving element, or **rotor**, consisting of a number of bars short-circuited on each end by rings, is shown in Fig. 231. On account of its construction, this type is known as "squirrel



4-Pole, 24-Slot, 83⅓% Pitch.

Fig. 230. — Winding Diagram for Four-Pole, Three-Phase Induction Motor.

cage." It has no electrical connection with any outside source of power, the currents in it being induced by the changing magnetic field, hence the name **Induction Motor.**

To a certain extent, an induction motor is a special application or adaptation of the principle upon which an alternating-current transformer operates. For this reason the winding connected with the source of power is often called the primary, and the element in which the current is induced, is called the secondary. In ordinary commercial motors it is customary to have the primary winding placed in the stator, or stationary frame of the machine. As this is the only winding connected

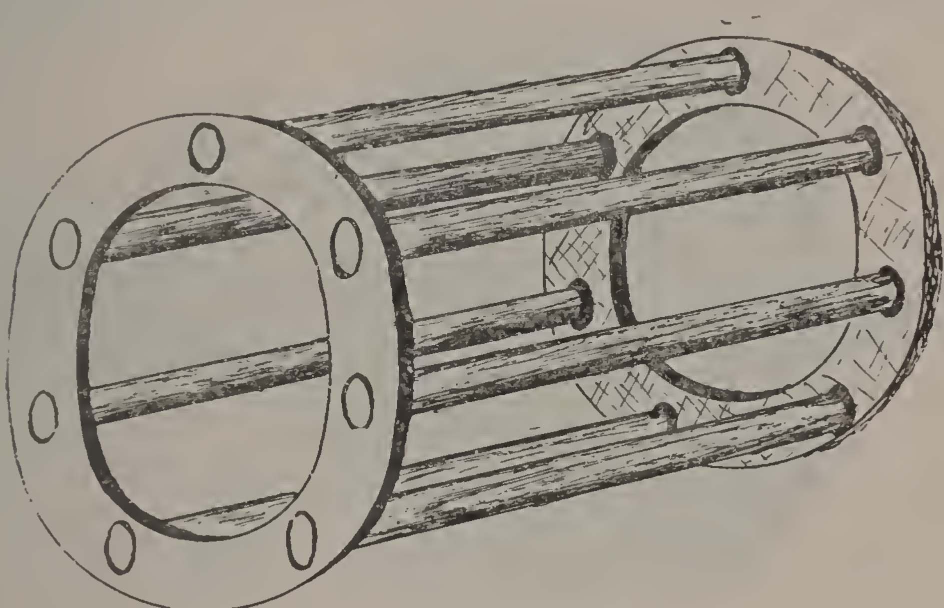


Fig. 231. — Squirrel-Cage Rotor Winding.

to a source of power, this simplifies the machine and avoids sliding contacts and brushes.

For variable speed work, or when a particularly large turning effort or "torque" is desired in starting, such as on crane work, wound rotors are sometimes employed and external resistances are connected in series with these windings by means of slip rings and brushes. The reason for this will be apparent from a consideration of the following paragraph.

If the bars of a squirrel-cage rotor are large and of low resistance, large currents are produced in them even though they cut a comparatively small

number of lines of force; consequently such a rotor will run with very little slip, and its speed will be reduced very little by an increase in the load it must drive. On the other hand, such a rotor has the peculiar effect of reducing the torque of the motor when starting up or running at speeds greatly below synchronism, although the current flowing becomes very large.

The induction motor is adapted to many uses that would be impossible for other motors, from

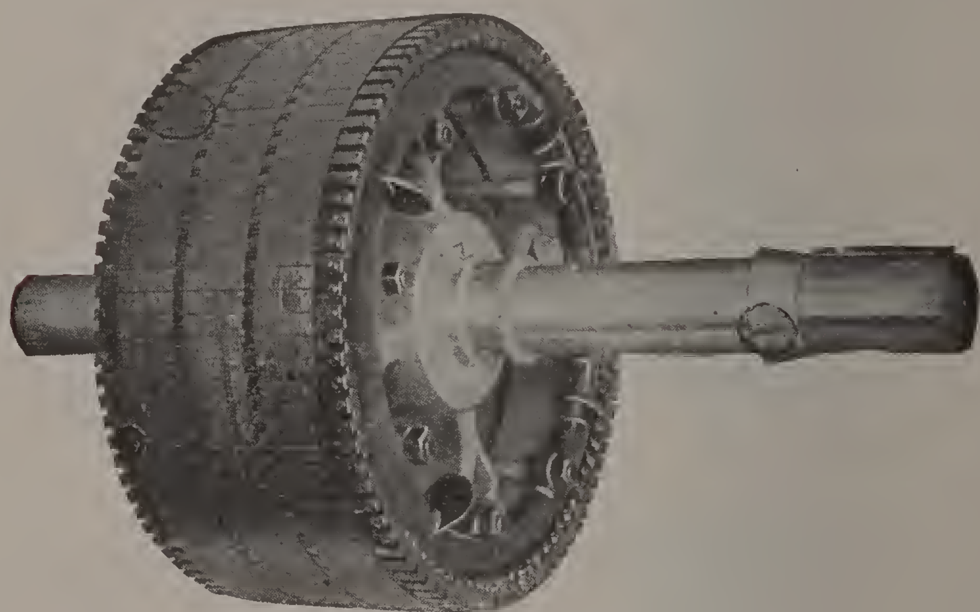


Fig. 232. — General Electric, Form K, Squirrel-Cage Rotor.

the fact that no brushes or slip rings or commutators or other bare or moving parts carrying current are required (currents in the squirrel-cage rotor being of very low voltage and flowing entirely in itself, much like eddy currents). All the parts that are connected to the supply wires are stationary and may be covered with heavy insulation. Fig. 233 shows an induction motor, built by the Lincoln Electric Company, in which the current carrying parts are so well insulated and other parts are so designed that it will operate even under water.

We have seen that an alternating current in the stator of an induction motor, produces a revolving field. We have also seen in Chapter XXI, that a revolving field produces an alternating current in a stationary armature winding. Now an alternator armature winding is, in principle, the same as the stator winding for an induction motor of the same number of poles and phases.

Let us remove the rotor from an induction motor, and substitute a revolving field structure similar to that in Fig. 117, with the field magnets

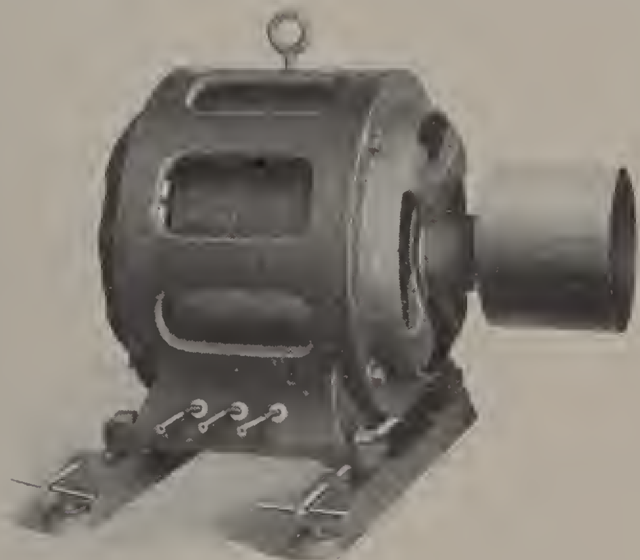


FIG. 233. — TYPE I, INDUCTION MOTOR.
LINCOLN ELECTRIC CO.

excited. We will also cause this field to revolve at the same speed and in the same direction as that of the stator. If we keep each north pole of this new rotor opposite a south pole in the stator field, and *vice versa*, there will be an attraction between them. Now a little reflection will show that if either field tends to run slower, this attraction will speed it up and keep it opposite the other. If the rotor field is driven a little ahead of the stator field, current is generated in the stator windings and sent out on the line, and we have a regular alternating current

generator. If the rotor is not driven but is connected to a load so that it lags a trifle behind the stator field, the latter exerts a pull, and keeps it running as a motor. In this case, energy is supplied to the stator winding from the line, to maintain the pull on the rotor.

An alternator, then, will run as a motor if current is supplied to it. It makes no difference whether the armature or the field-magnets revolve, the effect will be the same. A machine built to be driven in this way by alternating current is called a **Synchronous Motor,** because it must always run at synchronous speed. This speed it will be seen is exactly that of the generator which supplies the current if generator and motor have the same number of poles.

If we recall now the discussion of the direct-current dynamo in Chapter X, we will remember that the current flowing in each coil is alternating and that a commutator is necessary to rectify it into direct current. We are now prepared to notice that each coil on a direct-current armature generates an alternating electro-motive force that is different in phase from that generated in every other coil on the armature. If, however, taking those coils in which the phases are most nearly alike for one phase, we divide the winding up into sections corresponding to the number of phases required, we can put a set of slip rings on the armature at the other end from the commutator, connect them to the points of division, and take direct current from one end and alternating from the other end of the same armature.

We should notice, however, that if the machine is adjusted to furnish direct current at a certain voltage, it will give a certain voltage at the alternating current end. Changing the voltage of either will change the other.

Such a machine, then, will furnish both direct and alternating current, or it will furnish either

alone. It will run as a motor if supplied with either kind of current — as a synchronous motor if alternating current is used. Also — and this is the important point — we can supply either kind of current to it, and obtain the other kind from it at the other end of the armature. When used in this way the machine is known as a **Rotary Converter.**

Rotary Converters are most largely used in electric railway work, where direct current of about 600 volts must be supplied to the trolley wires, and it is desired to transmit the power from a distance. It would require an enormous amount of copper to transmit the large currents used for any considerable distance, if no higher voltage were used. But by using alternating current and high voltage, the current, and therefore the wires, are small, and we can "step down" the voltage by means of transformers near the point where it is to be used, and then change it to the required direct current by means of rotary converters.

Synchronous motors must be brought up to speed and "synchronized" — that is, adjusted so that motor and line are in phase with each other — before connecting it to the line. Several methods of doing this are used. A small induction motor may be connected to its shaft, arranged to start it and bring it up to a speed somewhat faster than synchronism. Current is then cut off and it is allowed to "drift" down to the proper speed, and when exactly in phase, as shown by special synchronizing devices, it is switched onto the line.

A second, and more common method, is to supply the armature of the rotary converter or synchronous motor with alternating current at a voltage considerably lower than that of the line, obtained by means of low voltage taps from the transformers, or by starting compensators. The field is not excited until the machine has nearly reached synchronous speed. The armature will

act on the solid pole faces as on the bars of a squirrel-cage rotor, bringing it up to speed as an induction motor. Then the field-current is applied, locking the machine in step with the supply current.

Railway converters are sometimes started with a starting-box from the D.C. side, if there is direct current being supplied to the trolley at the time by another converter.

CHAPTER XXV

MOTOR CHARACTERISTICS

Characteristics of Shunt, Series, and Compound-Wound Direct-Current Motors — Characteristics of Alternating-Current Motors.

Generator characteristics have been explained in Chapter XX. Motors have more characteristic curves than generators, since there are more quanti-

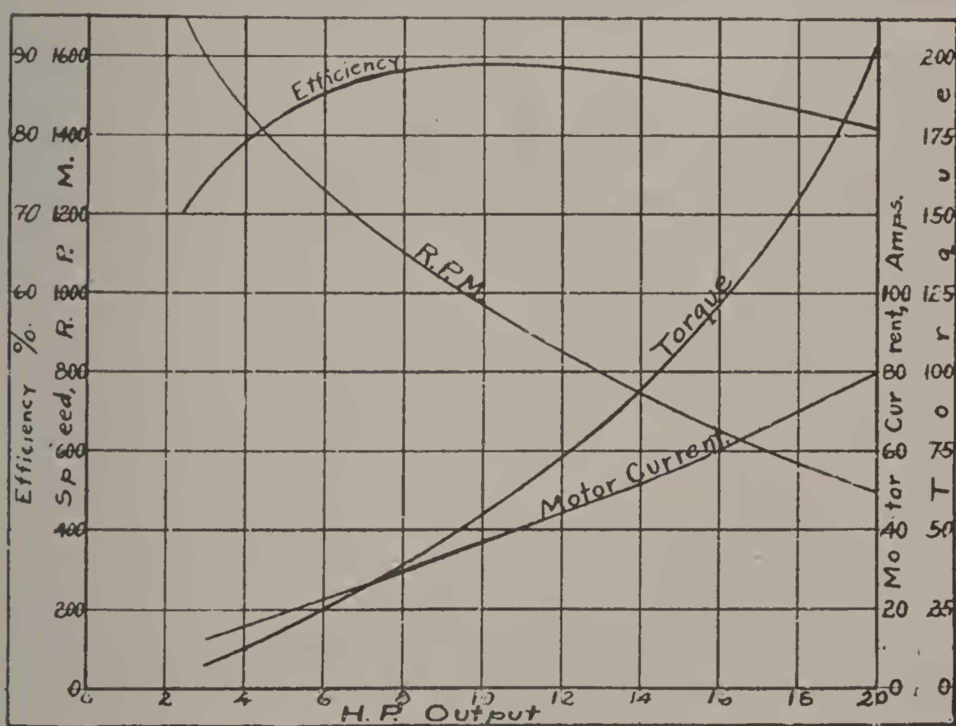


FIG. 234. — CHARACTERISTIC CURVES OF A SERIES MOTOR.

ties of interest to the designer or purchaser which will change with the load. The more important of these variables are speed, horsepower, torque, and efficiency.

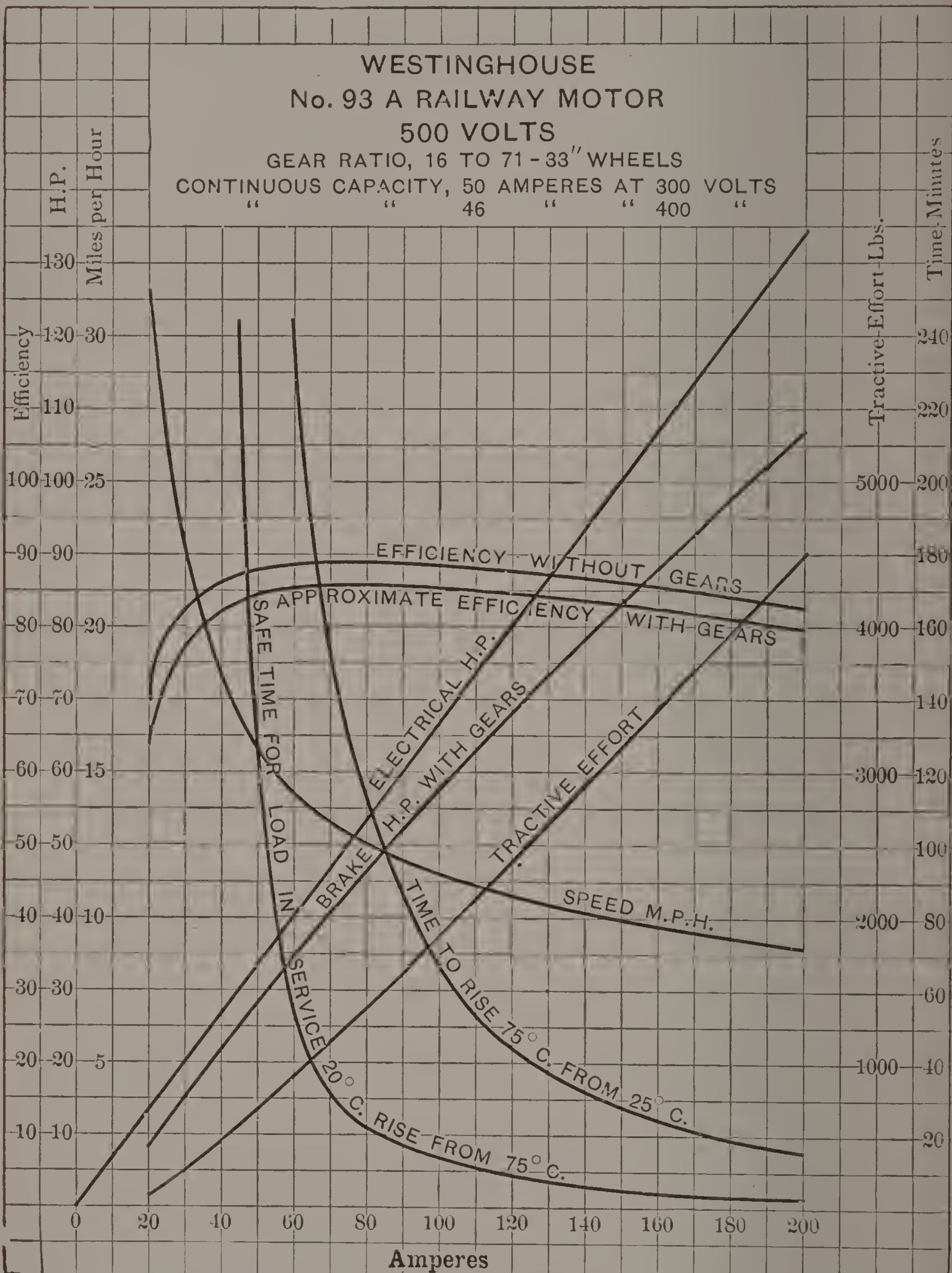


FIG. 235. — CHARACTERISTIC CURVES OF WESTINGHOUSE NO. 93 A SERIES RAILWAY MOTOR, GEARED TO CAR AXLE. GEAR RATIO, 16 TO 71. WHEELS, 33″ DIAMETER.

The **torque** depends not only on the armature current, but on the strength of field as well. For this reason, where strong turning efforts are required, especially at starting, series field windings are used so that with a heavy load not only the armature current but also the field is strengthened. In shunt field motors, extra torque is gained only by added armature current, the field strength being practically fixed. To better understand each machine, let us consider their characteristics separately.

Fig. 234 shows characteristic curves of a 10-H.P., 230-volt, 1000-R.P.M. series motor. In this diagram the horsepower developed by the motor is plotted as abscissas and used as the basis on which other data are shown. Values for the ordinates of speed and efficiency curves are given on the left, those for torque and motor current on the right.*

The curve of R.P.M. shows that while the speed falls off on heavy loads, on light loads it runs up to very large values. This curve gives 980 R.P.M. at full load, 1350 at half load, and 505 at double load. If the load were entirely disconnected, the speed would become excessive, causing armature and commutator to fly to pieces, because of centrifugal strains. It is, therefore, always necessary to direct-connect a series motor to its load. Belts should never be used, as they are liable to break or fly off on overloads.

Note that at rated H.P. the torque is 55 lb.-ft., while at 20 H.P. it is 200 lb.-ft., nearly four times the torque at double load, whereas a shunt machine would show only a little over double torque on double load.

* Values of torque are given in pound-feet, or effective pull in pounds at one-foot radius. For example, if an armature has 200 conductors, and each conductor, at a distance of 10 inches from centre of shaft, has an average pull of 2.5 pounds, the torque or twisting effort would be $200 \times 2.5 \times 10 = 5{,}000$ pound-inches, or $5{,}000/12 = 416$ pound-feet.

This diagram also shows the efficiency curve or per cent. useful energy obtained from motor at different loads. The best efficiency on this particular motor is 89% at full load. The efficiencies at half load, 83.5%, and double load, 81%, show it to be well designed. Currents for different horse-power outputs are shown in motor-current curve. Motors requiring maximum torques and where change of speed with load is not objectionable are series wound. Railway motors require large torque to get a car or train under way, while as car speeds

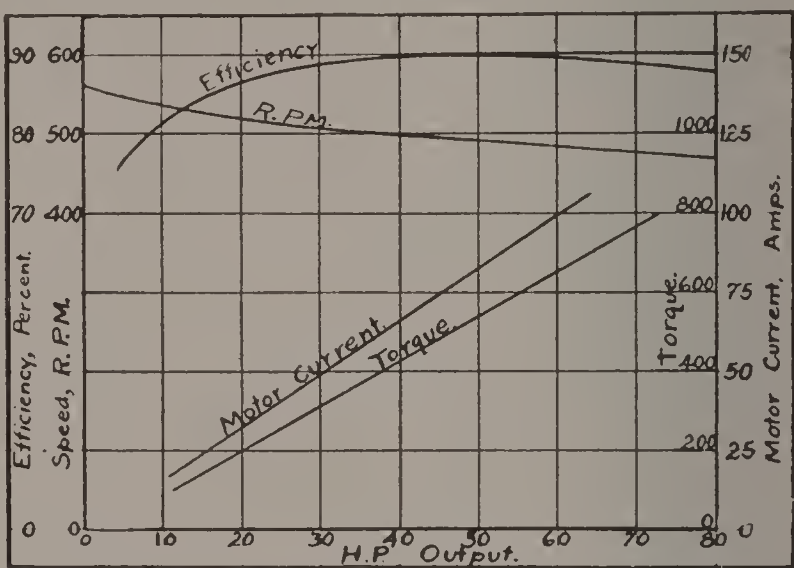


Fig. 236. — Characteristic Curves of a Shunt Motor.

up less torque is required. These requirements are ideally fulfilled by the series motor. So with other applications discussed in next chapter.*

* Fig. 235 shows curves for a No. 93A Westinghouse Railway Motor. These curves present many interesting facts concerning railway motors. The amperes input are given as abscissas, and all other values are plotted with reference to amperes input. These curves show not only speed, efficiency, horse-power, but the speed of car, and tractive effort or pull exerted at the rails, with 33-inch wheels and gear ratio 16 to 71, and also the time motor can be run under given loads to obtain specified temperature rises. This motor on a one-hour rating to give 75° C. rise shows 60 Brake H.P.

Fig. 236 shows characteristic curves of a 40-H.P., 500-volt, 500-R.P.M. shunt motor. These curves are similar to Fig. 234, except that speed varies little with load and torque curve is much less steep. Note that the torque goes up approximately with the load, and not rapidly as in a series motor. Also that the efficiency is a little higher than that of the 10-H.P. motor in Fig. 234. Larger motors have less percentage losses and therefore show higher

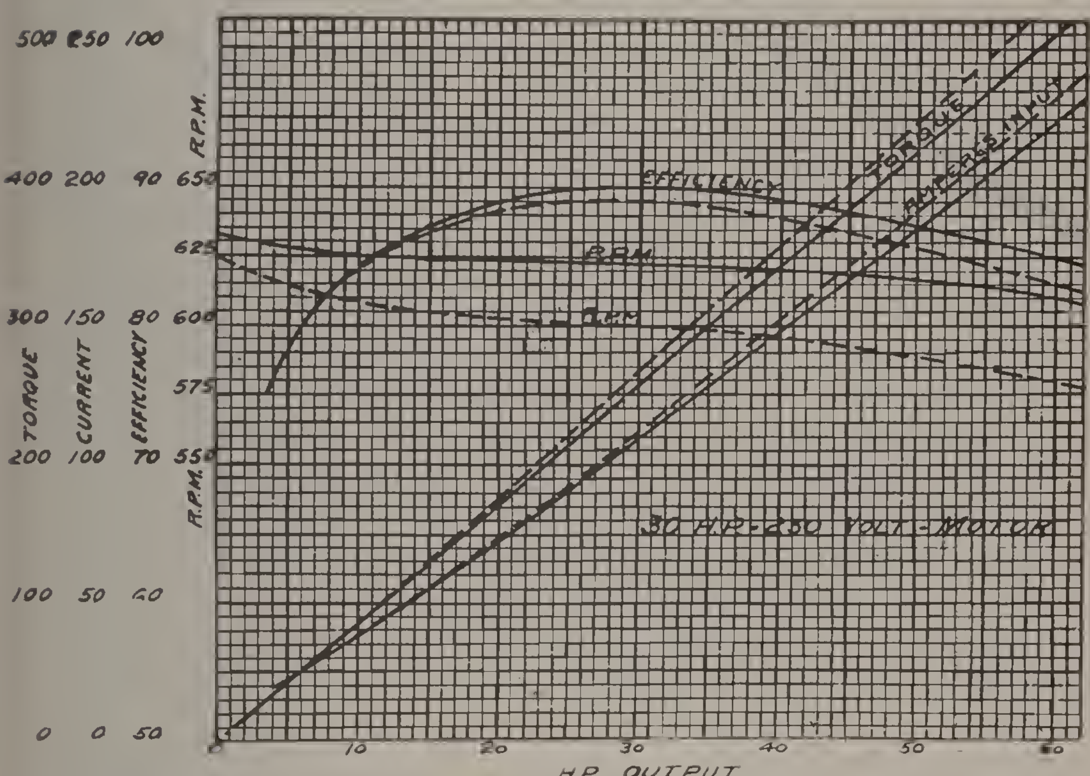


FIG. 237. — CHARACTERISTIC CURVES OF SHUNT MOTOR WITH AND WITHOUT COMMUTATING POLES.

efficiencies. For motors where constant speed at all loads is the essential, shunt windings are used. Shunt motors can be run with perfect safety at no load.

The addition of commutating poles to direct-current machines, as explained in Chapter XIX, not only increases the efficiency by reducing armature short-circuit currents but also affords better

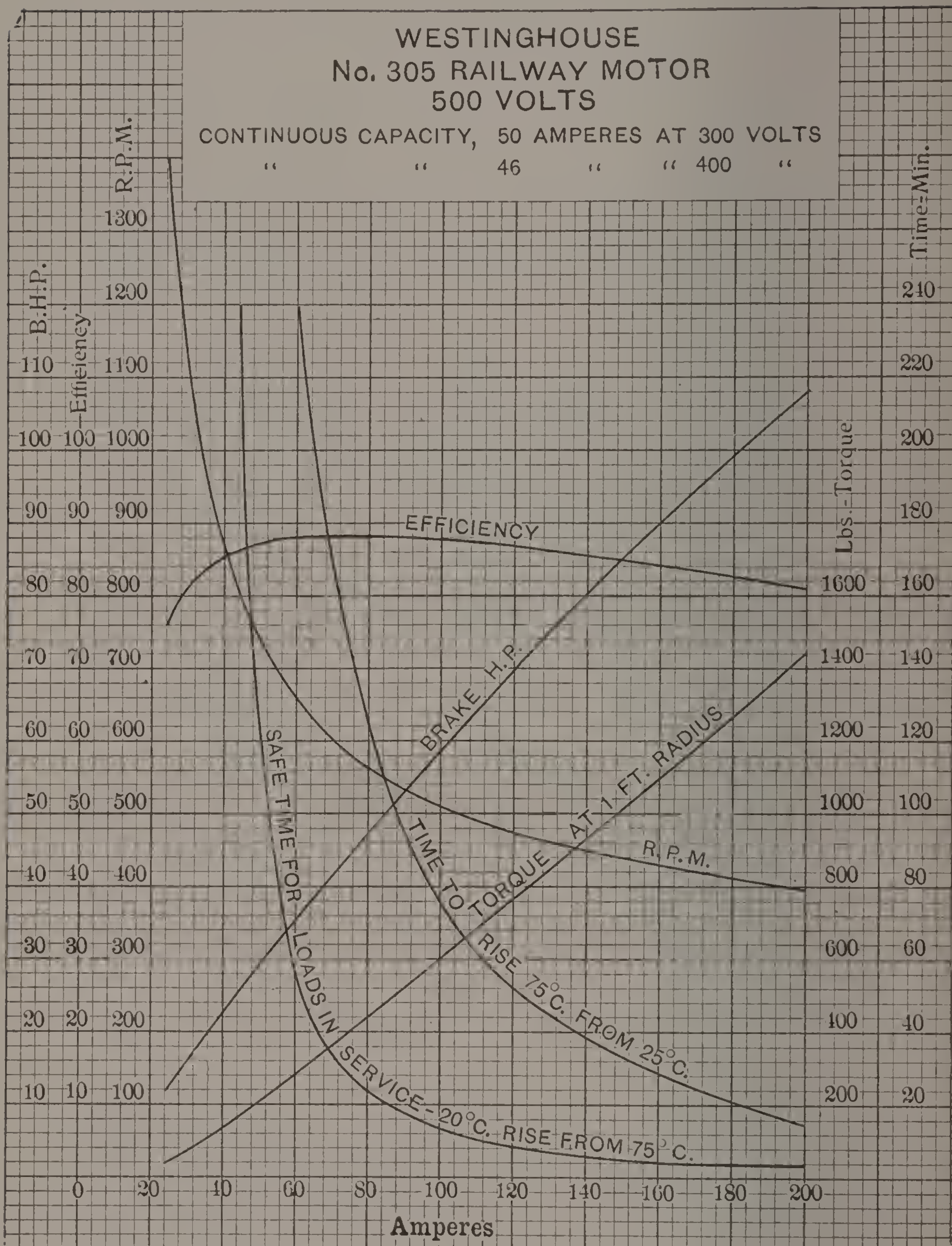


FIG. 238. — CHARACTERISTIC CURVES OF A WESTINGHOUSE INTER-POLE RAILWAY MOTOR.

speed regulation, that is, less change of speed from no load to full load. Fig. 237 shows curves of a 30-H.P., 230-volt motor with and without commutating poles; full-line curves with, and dotted without. Without these poles the speed goes from 625 R.P.M., at no load, to 600 R.P.M. at full load, a change of 25 R.P.M., or 4%, while the commutating poles show no load 632 R.P.M. and 623 R.P.M.

Fig. 239. — Westinghouse No. 305, 75 H.P., 600 V., Inter-Pole Railway Motor. Lower Frame Down for Inspection.

at full load, a difference of 9 R.P.M., or 1.5%. As commutating-pole machines are lighter and cheaper, they are coming into universal use, not only for stationary motors, but for series railway motors.

Compound motors are a combination of series and shunt. Generally they are series motors with sufficient shunt field to prevent motor racing on no

load, and curves are similar to Fig. 234, except speed and torque curves are less steep.

Characteristic curves for motors are obtained in two ways: First, by calculations from dimensions and electrical specifications. This method is accurate though very laborious, requiring many hours of slide-rule work. The experienced designer can plot curves showing every action of a new design of machine before even the patterns for castings or dies for punchings have been started.

Another and more rapid, though less accurate method, is to determine data from test and then plot the results. The method of obtaining these results is by the use of a "Prony Brake."

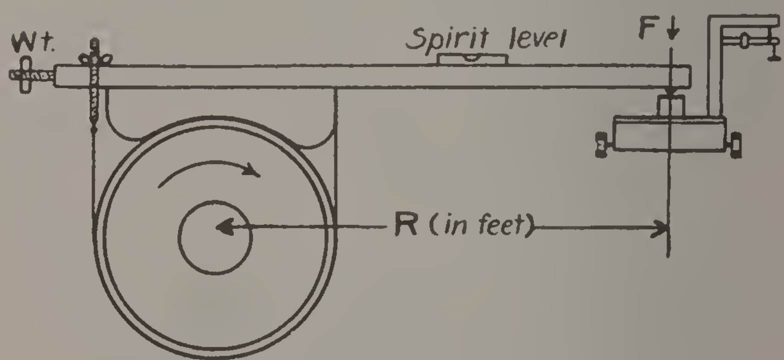


FIG. 240. — PRONY BRAKE.

Fig. 240 shows a Prony Brake. This consists of an arm made of wood or steel, depending on size, and a strap to put over pulley with turn buckle as shown. The strap is often fitted with small blocks of wood to take the wear, and pulleys are made special, with flat instead of crown face, and with side flanges on the inside of rim to hold water when in motion. The water boils and carries off the heat which otherwise would soon burn the wood blocks. The arm is generally balanced by a weight, as shown, so that when pulley is not revolving the scales show no reading. If arm is not balanced, a "tare" reading must be noted and subtracted from all scale readings.

Knowing the horizontal distance between center of shaft and point of support on scales, and the scale reading, the torque at any speed and current input can be determined. For example, suppose R is 3 feet, the scales give 17.6 lbs., current is read 29.1 amps. at 230 volts, and speed is noted to be 796. The torque may then be calculated as

$$T = 17.6 \times 3 = 52.8 \text{ pound-feet.}$$

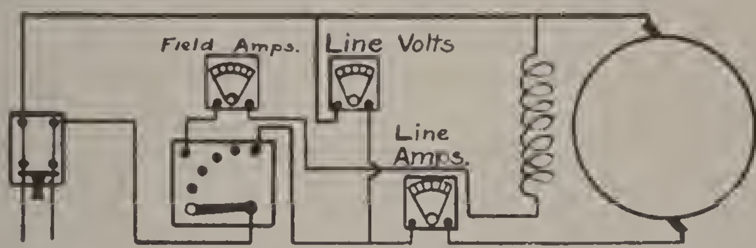


FIG. 241. — CONNECTIONS FOR BRAKE TEST. DIRECT CURRENT SHUNT MOTOR.

There are several simple formulae used to calculate data from a test of this kind, as follows:

$$\text{Torque} = T = \text{Length of Arm} \times \text{Net Weight}$$
$$= R \times F$$
$$\text{H. P. Output} = \frac{2 \times 3.14 \times \text{R.P.M.} \times R \times F}{33{,}000}$$
$$= \frac{\text{R. P. M.} \times T}{5250}$$
$$\text{Watts Output} = 746 \times \text{H.P. Output}$$
$$= .142 \times \text{R.P.M.} \times T$$
$$\text{Watts Input} = \text{Line Volts} \times \text{Motor Current}$$
$$\text{Efficiency} = \frac{\text{Watts Output}}{\text{Watts Input}}$$

A sample test on a 7.5-H.P., 800-R.P.M., 230-volt shunt motor with a 3-foot brake arm is given. Field current was .80 amperes during test. Volt-

age was held constant at 230. Tension on strap was varied from approximately 4 to 36 pounds. Speeds, currents and actual scale readings were noted at the same instants.

Readings.			Calculations.					
Armature Current	R.P.M.	Net Weight	Motor Current	Torque "T"	Watts Output	Watts Input	Effic. %	H.P. Output
8.8	830	4.2	9.6	12.6	1490	2210	67.5	1.99
15.1	815	8.6	15.9	25.8	2990	3660	81.7	4.00
21.9	805	13.0	22.7	39.0	4460	5230	85.4	5.98
29.1	796	17.6	29.9	52.8	5970	6880	86.8	8.00
37.0	788	22.2	37.8	66.6	7460	8700	85.8	10.0
45.0	783	26.8	45.8	80.4	8940	10500	85.0	12.0
54.0	777	31.5	54.8	94.5	10450	12600	83.0	14.0
63.5	773	36.3	64.3	109.0	12000	14800	81.1	16.0

Field Current, .8 Amperes. Brake Arm, 3 Feet.

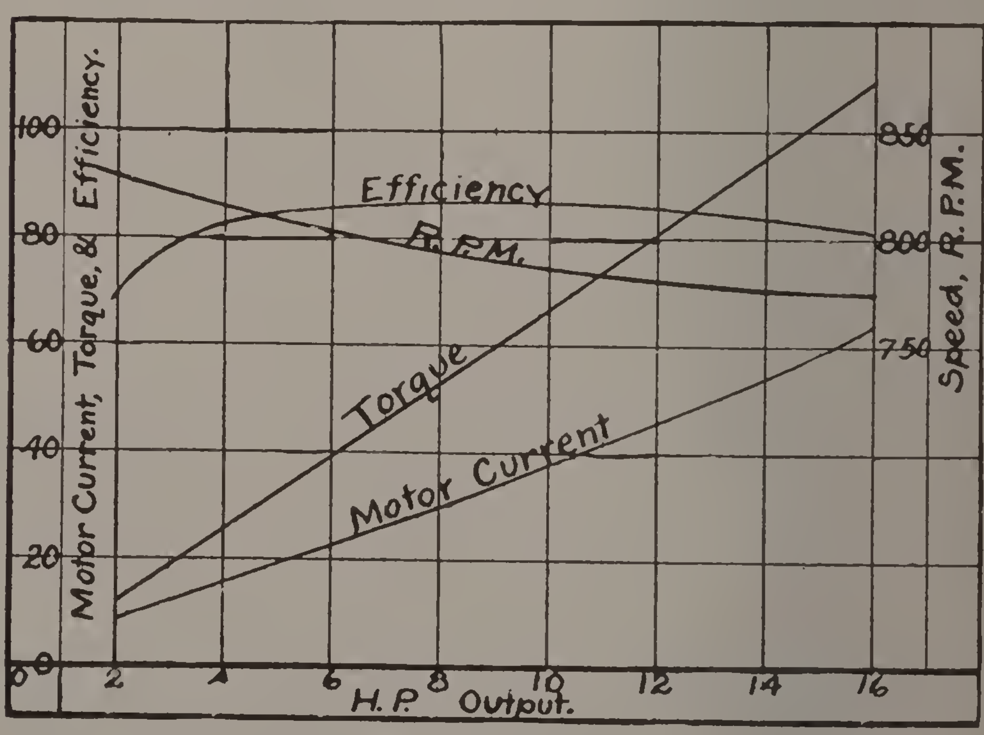


Fig. 242. — Curves Plotted from Brake Test.

Fig. 241 is a diagram of the electrical connections for this test. Fig. 242 shows a plot of these values. It is always desirable to repeat a test and plot average values. Tests should be run when motor is hot, that is, after having been run for several hours, otherwise the rise in temperature in fields causes an increase in resistance, decrease in current, and consequent increase in speed during the test, which is undesirable.

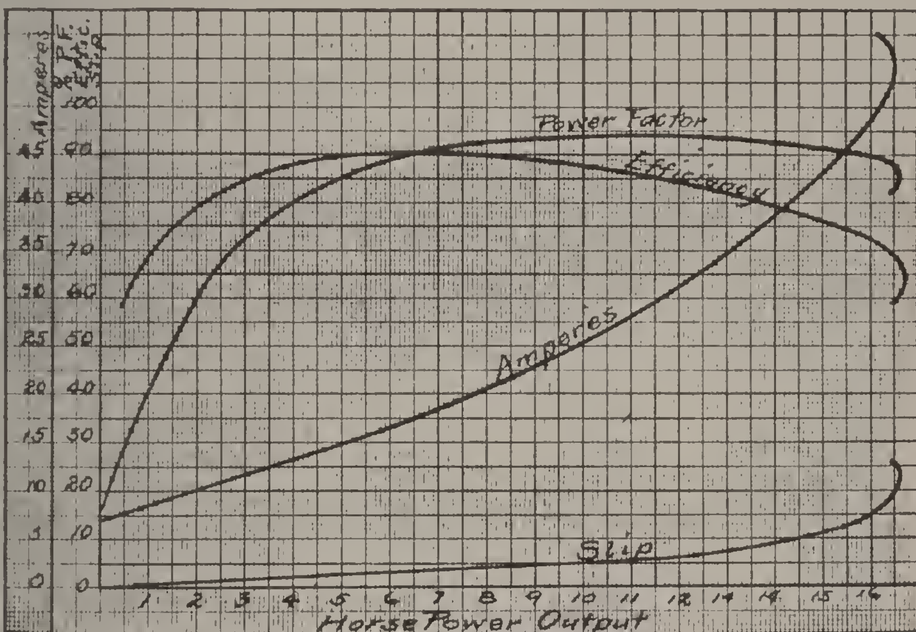


Fig. 243. — Characteristic Curves of Three-Phase Induction Motor. 7½-H.P., 4-Pole, 60-Cycle, 1800 R.P.M. Synchronous Speed.

Water brakes are used on high speeds, 3000 R.P.M. and above, also on large powers. The water brake consists of a disc or series of discs running in water. The housing is balanced and through an arm transmits the twist to scales which measure twist in pounds, the water acting as a medium instead of the belt in the brake shown in Fig. 240. The water is piped so as to flow continuously through the brake when desired.

Prony brakes can be used to measure the power of any engine or shaft as well as a motor by a modification of design. A convenient method of measuring the power required by machine tools is as follows: Carefully test a motor and plot curves. Then drive the machine tool by this motor and note current. With this value of current, read off from curve the horsepower to drive the machine in question.

The characteristic curves of induction motors are very similar to the direct-current curves, and can likewise be either calculated or determined from a brake test. Fig. 243 shows curves of a 7.5-H.P., 1800-R.P.M., 220-volt polyphase motor. Horse-

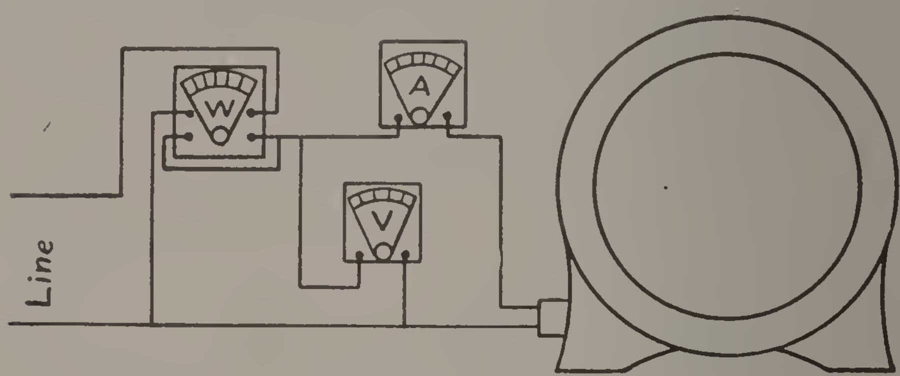


Fig. 244. — Connections for Brake Test. Single-Phase Motor.

power output is used as a base line, and efficiency, power factor, amperes input and slip are plotted, showing their several relations to the horsepower output.

Unlike direct current, the product of the readings of ammeter and voltmeter does not show the real power consumed, but a value called "apparent power." The wattmeter shows the real power. The real power divided bv the apparent power is called the **power factor.** This value can be at once calculated from instrument readings.

Fig. 244 is the diagram of a single-phase motor connected for brake test, while Figs. 245 and 246

show connections for three and two-phase motors. For the power input of a polyphase motor, always take the algebraic sum of the wattmeter readings.

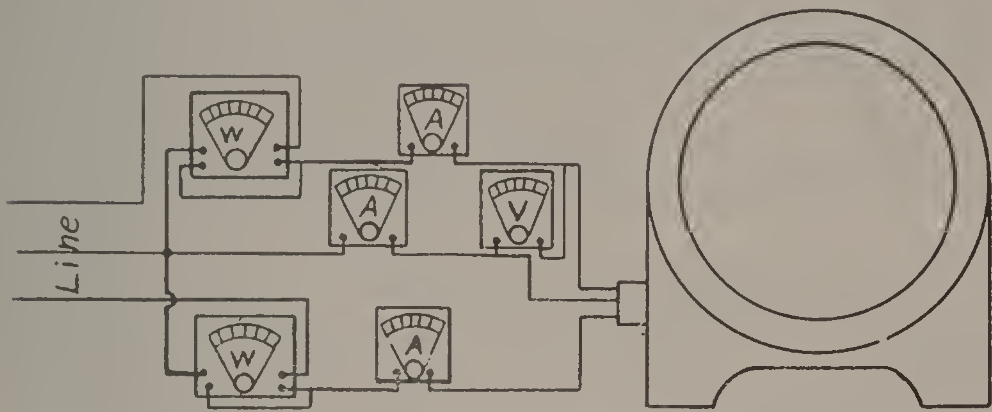


Fig. 245. — Connections for Brake Test. Three-Phase Motor.

To get the watts expended in each phase, divide this sum by the number of phases. Except in very special tests, power losses in the measuring instruments are neglected. Values for efficiency curve are then calculated as for direct-current machines.

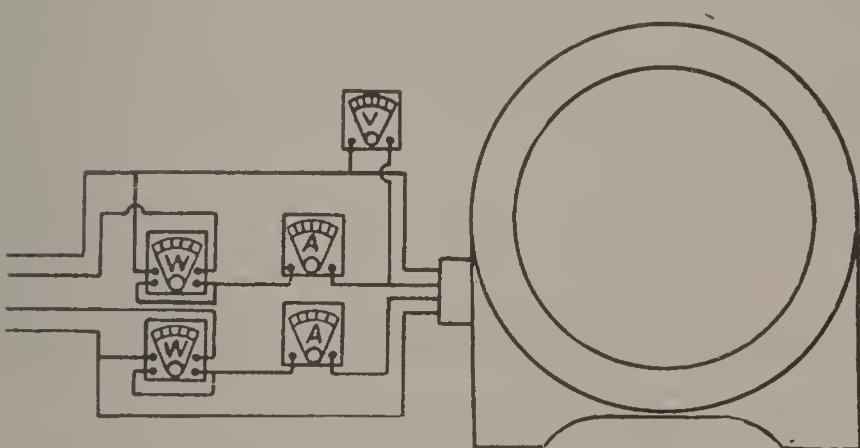


Fig. 246. — Connections for Brake Test. Two-Phase Motor.

The current-input curve represents current per phase in the case of a polyphase motor, and is taken as the average of ammeter readings.

As has been noted in a preceding chapter, an induction motor cannot run at synchronous speed, but must have a certain amount of slip to provide the torque necessary to carry the load. Now the synchronous speed is dependent on the frequency and number of poles, as follows:

$$\text{Synchronous Speed} = \frac{\text{Frequency} \times 120}{\text{Number of Poles}}$$

The actual speed of the motor is less than this amount, and the slip is expressed as a per cent. of synchronous speed, as follows:

$$\text{Slip} = \frac{\text{Synchronous} - \text{Actual Speed}}{\text{Synchronous Speed}}$$

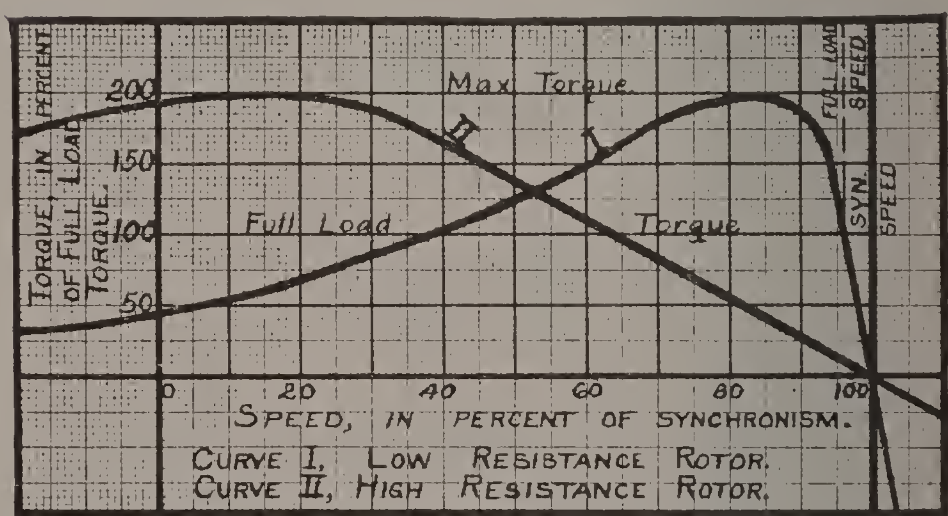


FIG. 247. — SPEED-TORQUE CURVE OF AN INDUCTION MOTOR.

A very interesting curve, and one which shows at a glance some of the more important characteristics of an induction motor, is the speed-torque curve, Fig. 247. Curve I is for a motor with low-resistance rotor winding. The effect of this winding in reducing the starting torque is plainly seen, as well as its effect at all speeds. The maximum torque

is developed at a speed of about 85% of synchronous speed, then falls off rapidly as the motor reaches its running speed, which is found by locating the point on the curve at which the required torque is developed. This part of the curve is very steep, showing small changes in speed for large changes in load. If the motor is driven so as to run faster than synchronous speed, the torque is negative. If backwards, the opposing torque becomes less and less as the speed increases.

Curve II shows the effect of inserting resistance in series with the rotor. The speed at full load is less, *i.e.*, the slip is greater, than in the case of Curve I, the speed of maximum torque is less than before and the torque at starting is very much higher. It is readily seen that the maximum torque can be located at any speed desired, by inserting the required amount of resistance. This is the reason wound rotors with external resistance are used for elevator and crane motors.

The following formulae are for use in alternating-current calculations. They will be taken up and fully explained, together with other characteristics of alternating current apparatus, in Vol. II of this text book.

To calculate the watts power when current per phase, volts, and power factor are known:

$$\text{Single-Phase, } P = E \times I \times \text{P.F.}$$

$$\text{Two-Phase, } P = 2 \times E \times I \times \text{P.F.}$$

$$\text{Three-Phase, } P = \sqrt{3} \times E \times I \times \text{P.F.}$$
$$= 1.732 \times E \times I \times \text{P.F.}$$

To calculate line current per phase when the power in watts, voltage, and power factor are known:

$$\text{Single-Phase, } I = \frac{P}{E \times \text{P.F.}}$$

$$\text{Two-Phase,} \quad I = \frac{P}{2 \times E \times \text{P.F.}}$$

$$\text{Three-Phase,} \quad I = \frac{P}{\sqrt{3} \times E \times \text{P.F.}}$$

To calculate line current per phase when voltage, power factor and horsepower of the motor are known:

$$\text{Single-Phase,} \quad I = \frac{\text{H.P.} \times 746}{\text{Eff.} \times E \times \text{P.F.}}$$

$$\text{Two-Phase,} \quad I = \frac{\text{H.P.} \times 746}{\text{Eff.} \times 2 \times E \times \text{P.F.}}$$

$$\text{Three-Phase,} \quad I = \frac{\text{H.P.} \times 746}{\text{Eff.} \times \sqrt{3} \times E \times \text{P.F.}}$$

$$\text{Direct-Current,} \quad I = \frac{\text{H.P.} \times 746}{\text{Eff.} \times E}$$

In these formulae:

P = Power, in Watts
E = Electromotive Force in Volts
I = Current in Amperes
Eff. = Efficiency
P.F. = Power Factor
H.P. = Horsepower

CHAPTER XXVI

MOTOR DRIVE

Transmission of Power — Mechanical — Electrical — Efficiency of Transmission — Adjustable Speed Motors — Applications to Which Each Kind of Motor is Especially Suited — Power Required for Machines.

The transmission of power mechanically from a source of generation to the place of utilization

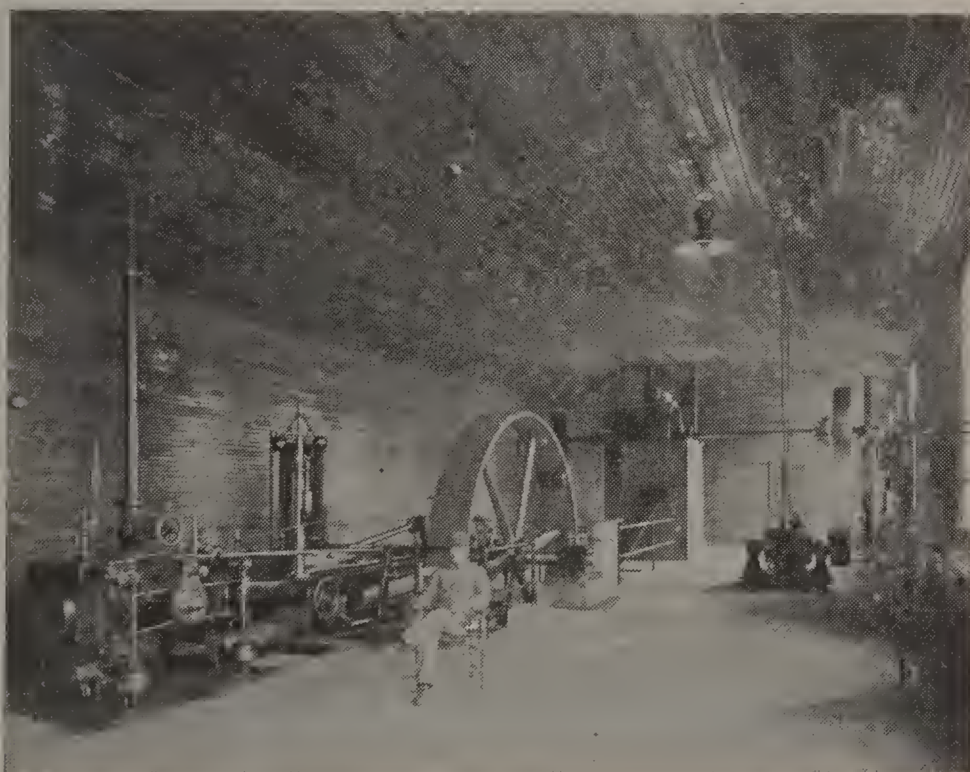


Fig. 248. — Corliss Engine Belted to Line Shaft.

requires shafting, belting, rope drive, or often gears. We are familiar with the factory in which one or

more slow-speed reciprocating engines, drive a heavy line shaft from which belts extend to other shafts and countershafts throughout the plant, with noise, dirt, and confusion, poor light and restricted vision.

The change wrought when electric is substituted for mechanical transmission in such a factory, is a revelation to one not acquainted with the benefits derived from motor drives. Belts and

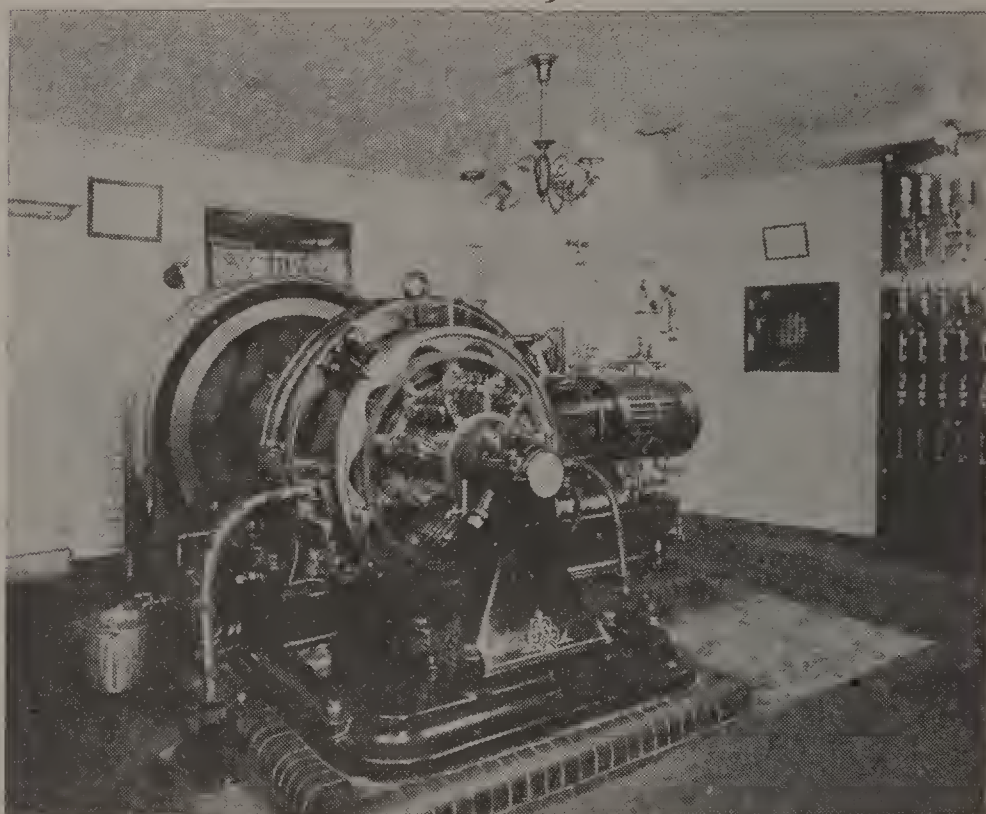
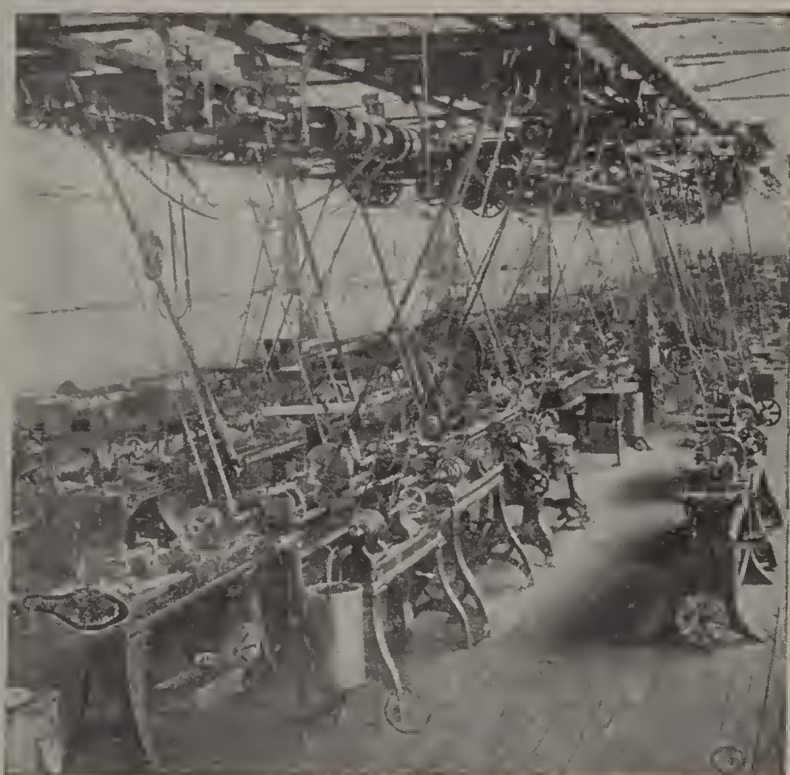


FIG. 249. — DIRECT-CONNECTED GENERATING SET. RIDGWAY DYNAMO AND ENGINE CO.

shafts give way to clear space, free air and head room, light is unobstructed, and the walls and ceilings, which moving belts blacken and give a smoky appearance, can be kept white and clean. Noise is limited to the machines themselves, and to those alone which are in actual operation, and the factory takes on a general appearance of order and arrangement. And these are not the only, nor, indeed, in

the eyes of many managers, the most important considerations.

Besides involving a high first-cost for equipment, the mechanical distribution of power is very inefficient. Usually 20 to 40% and in some cases as high as 60 or 75% of the power developed by the engines or water wheels is lost in transmission and never reaches the machines for which it was in-



(By permission of the General Electric Co.)

FIG. 250. — GROUP OF LATHES, BELT DRIVEN.

tended. For example, a 250-H.P. engine run at full load loses 30% or 75 H.P., in bearings, belts, etc. In a year the power thus wasted will represent a large sum.

Sometimes clutches are arranged to cut out parts of the shafting so that any particular part of the factory may be run alone. These, however, are seldom installed, and usually it is necessary to run

the entire system when one part of the factory, or even a single machine, is to be operated overtime. Thus if only 25 H.P. were required to operate one room at night, the engine mentioned above would have to deliver nearly 100 H.P. Also, besides inefficiency, the maintenance cost of such a system is high, requiring constant attention, tightening

(By permission of the General Electric Co.)

Fig. 251. — Group of Lathes, Motor Driven.

belts, oiling and rebabbiting bearings, which are often in awkward and inaccessible places.

The modern method of motor drive makes it possible to replace the large slow-speed engines by lighter and smaller high-speed engines or turbines, requiring much less floor space and head room — often an important consideration in city installations. With electric-motor drive, the engine and

generator can be placed in any part of the factory, regardless of line shafting. Wires or cables carry the power to the switchboard, and thence to the several departments of the factory where power is used, through walls or floors, around corners or angles — anywhere out of the way — wherever wire

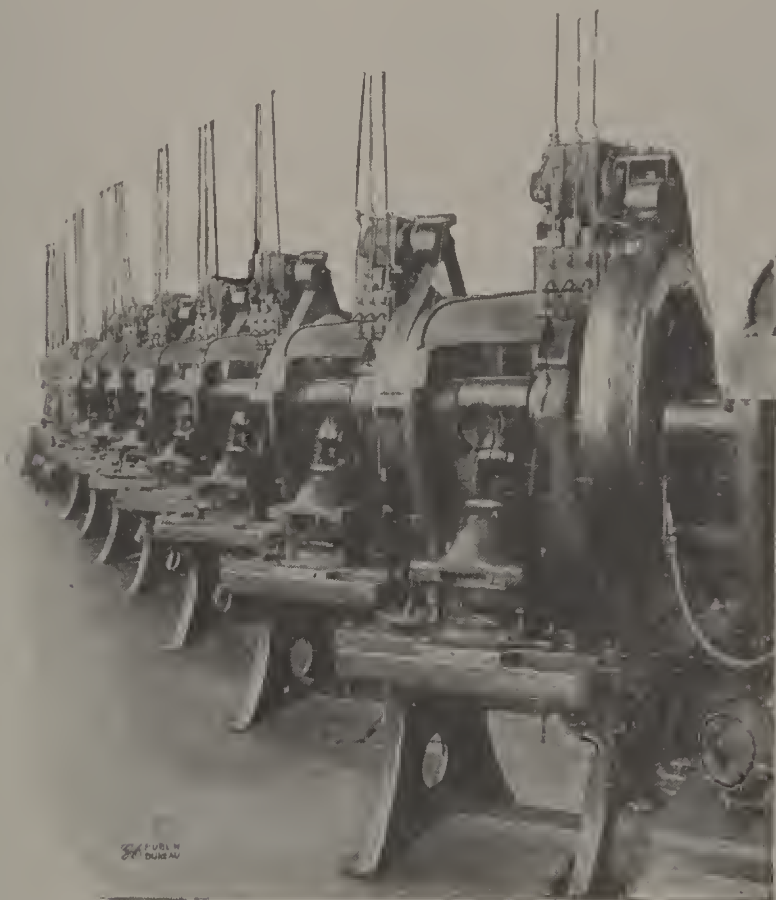


Fig. 252. — Group of Punch Presses, Operated by General Electric Induction Motors.

Note that presses are arranged for economy of floor space in handling stock and scrap. This grouping would be impracticable if presses were driven from line shafting.

can be strung. Corners or angles that would cause serious losses in belting or gearing in no way affect the electric transmission line.

Let us consider some of the ways in which the power consumption is reduced and power bills cut down by motor drives.

In the first place, power losses in transmission-line wires do not often exceed 5% and are often lower than this. Motor efficiencies range from 80% in small sizes or at light loads, up to 90 or 92% in larger capacities. Thus we see when all machines are running, the losses are only 10 to 25%, as opposed

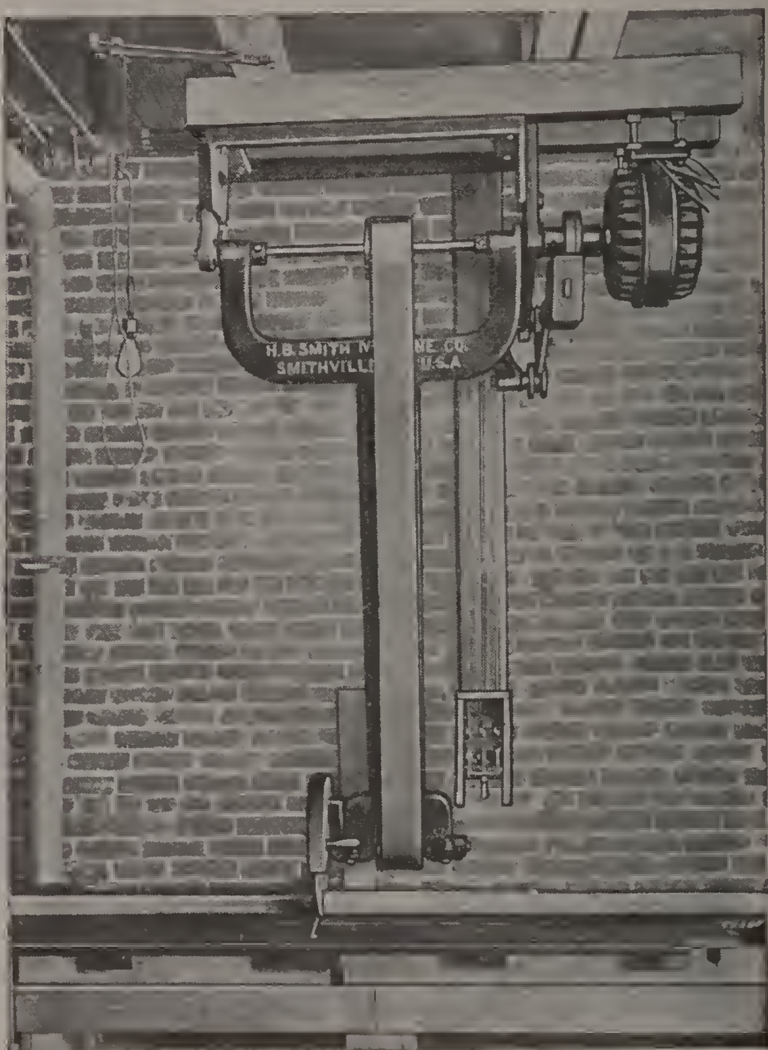


FIG. 253.—WESTINGHOUSE POLYPHASE MOTOR, DRIVING SWING SAW.

to the heavy losses incurred in mechanical transmission.

Again, in the old-fashioned factory, when any machine is shut down, the engine is relieved of only the actual power taken by the machine. The losses

incident to getting power to the machine go right on. In the modern factory, when a machine stops, not only the power used by the machine stops, but

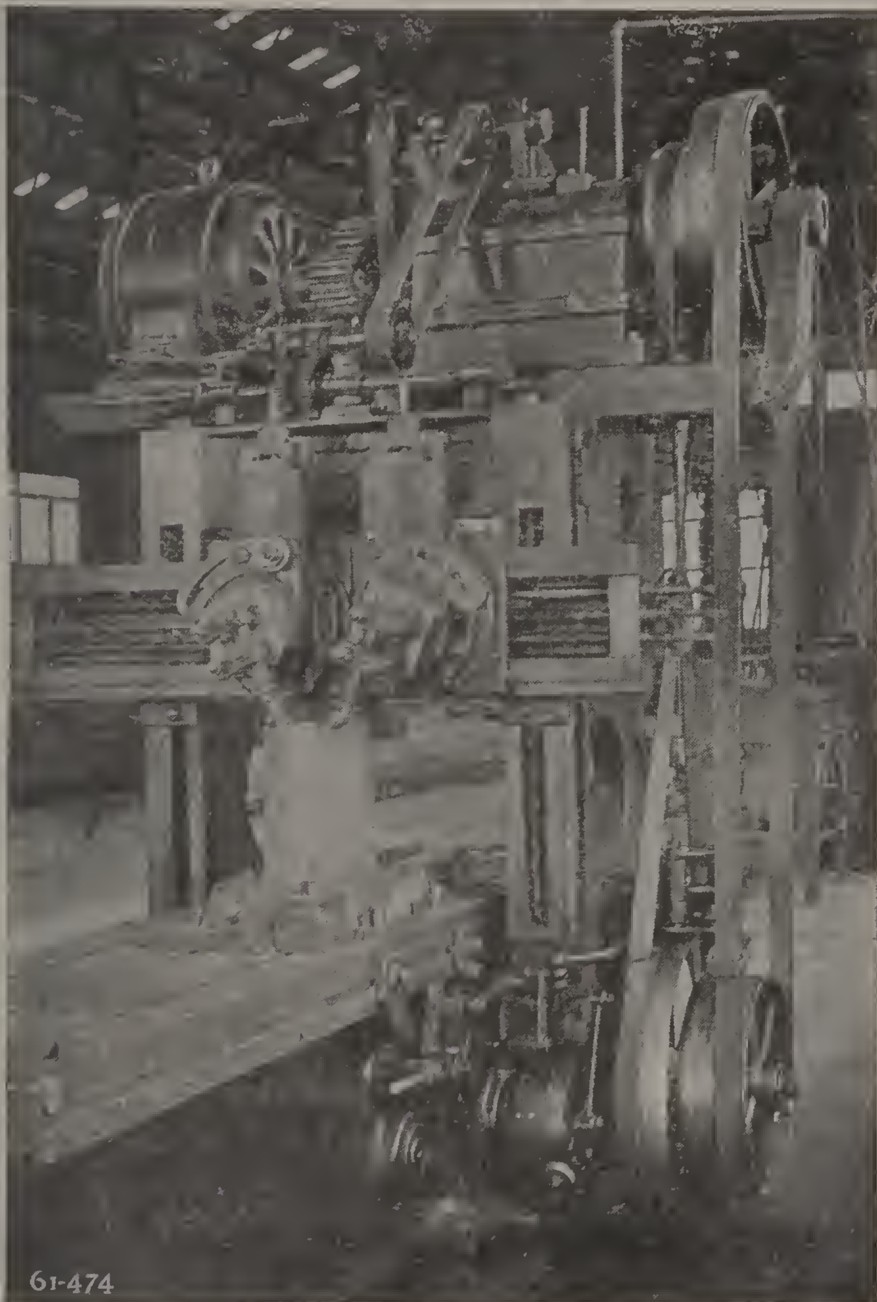


Fig. 254. — Wagner Polyphase Induction Motor, Operating a Planer.

also the losses in the transmission line. While in any case, wire losses are a very small consideration,

yet it may be worth while to note that these losses are reduced, not in *proportion* to the power, but in proportion to the *square* of the power. For instance, three machines connected to one line are taking 1000 watts each, with a loss of 90 watts or 3% in the line. One machine is shut down. Now the wire loss is $3000^2 : 2000^2 = 90 : X$, whence

$$X = 90 \times \left(\frac{2000}{3000}\right)^2 = 40 \text{ watts.}$$

FIG. 255. — WAGNER POLYPHASE INDUCTION MOTOR, OPERATING ENDLESS PAN CONVEYOR.

This is 2% of the power, 2000 watts, instead of 3% or 60 watts, as it would be if the loss were directly proportional to the power.

Another way in which power consumption is reduced has its basis in the ease with which electric power is measured. The engineer formerly had no way of telling how much load his engine was carrying, except in a general way, from its sound

and behavior, or by tedious calculations from indicator cards. Even then he could not tell what part of the factory was throwing an excessive load on the engine. With electrical equipment, the engineer can tell by a glance at the switchboard measuring-instruments just what the total load at the time is, how much is used in each part of the factory, or whether the load is constant or fluctuating. If

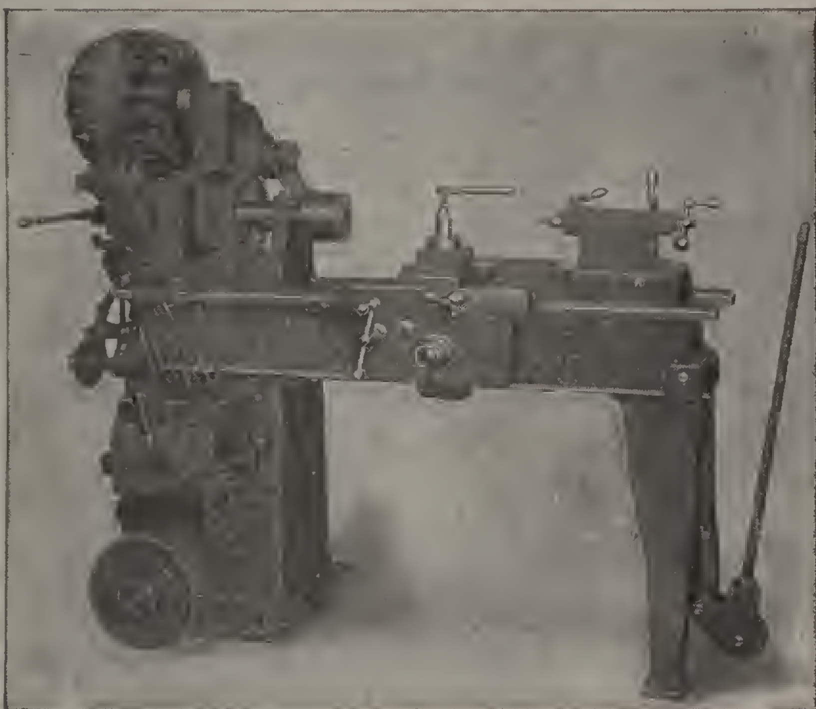


Fig. 256. — Westinghouse Polyphase Induction Motor, Geared to Portable Lathe.

any part of the factory is taking more power than usual, it is an easy matter to follow it down to some particular machine, and perhaps locate and remedy a defect that would have consumed a great deal of power before being noticed in an old-time factory.

Before deciding on the kind of power or type of motors to be adopted, the characteristics of the various types should be studied with special reference to the case in hand. There is an electric motor adapted to almost every power requirement.

Motors are frequently built into the machines they are designed to operate, so as to become a part of the structure. If specially constructed, motors can be operated under water. By the use of enclosing covers they can be operated in powder mills, saw mills, cotton mills, or other places where sparks would be destructive. Great advances have already

Fig. 257. — Westinghouse Electric Locomotive.

been made in the field of steam railroads, where electric locomotives are replacing steam. On battleships, almost every motion is accomplished by motor-drive. Guns are raised or lowered, their breeches opened and closed, ammunition hoisted and turrets revolved by specially constructed motors; doors connecting the water-tight compartments are closed by powerful motors; anchors are drawn, ventilating and exhaust fans and pumps operated.

For most purposes where a constant speed is desired, the induction motor is far superior to direct-current machines in general reliability and lower cost of maintenance. Wherever possible, and if

there are no other considerations which take precedence over these, the induction motor should be used.

In some cases where the speed *must* be *exactly* the same under varying loads, synchronous motors are used. However, synchronous motors are prone to trouble, both in starting and operation, unless handled by one familiar with them.

If adjustable speed is required, the direct-current motor is superior. Adjustable-speed induction motors are expensive and cumbersome. Speed re-

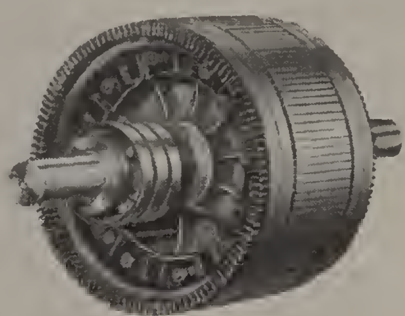


Fig. 258. — Wound Rotor, General Electric, Type M.

duction is accomplished by introducing resistance in the circuit of the rotor, which has, in this case, a regular armature winding provided with slip rings which connect with a variable external resistance. Fig. 258 shows the General Electric type M wound rotor with collector rings.

To understand the effect of this resistance, refer to the discussion of speed-torque curves, Fig. 247, in the previous chapter. By adjusting the resistance to the required value, the torque necessary to carry the load can be developed by the motor at any desired speed. It is apparent that the speed is very unstable with large resistance in circuit, as slight variations in load will produce great changes in speed. Also, under load, a great deal of energy is wasted in the resistance. Induction motors are sometimes so wound that the number of poles may be changed by means of a controller which makes

different connections. This, however, gives a very limited number of speeds with large steps between.

Coming now to the consideration of direct-current motor characteristics, we will take up the three general classes: series, shunt and compound.

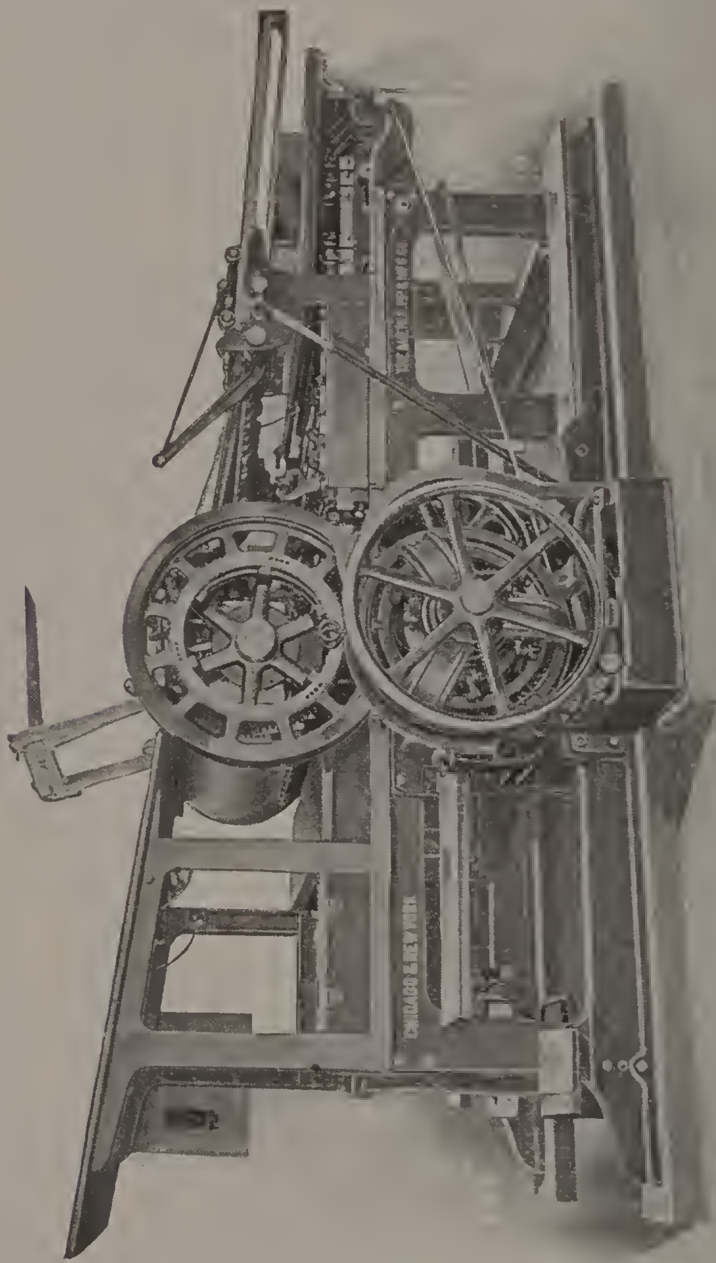


Fig. 259. — Sprague Slow-Speed Motor, Direct-Connected to Printing Press.

Commutating poles are adapted to all three, increasing their stability and fitness for commercial demands.

Each type has its own field of usefulness — sèries motors where large starting torque is required and speed variation with changes in load is not a

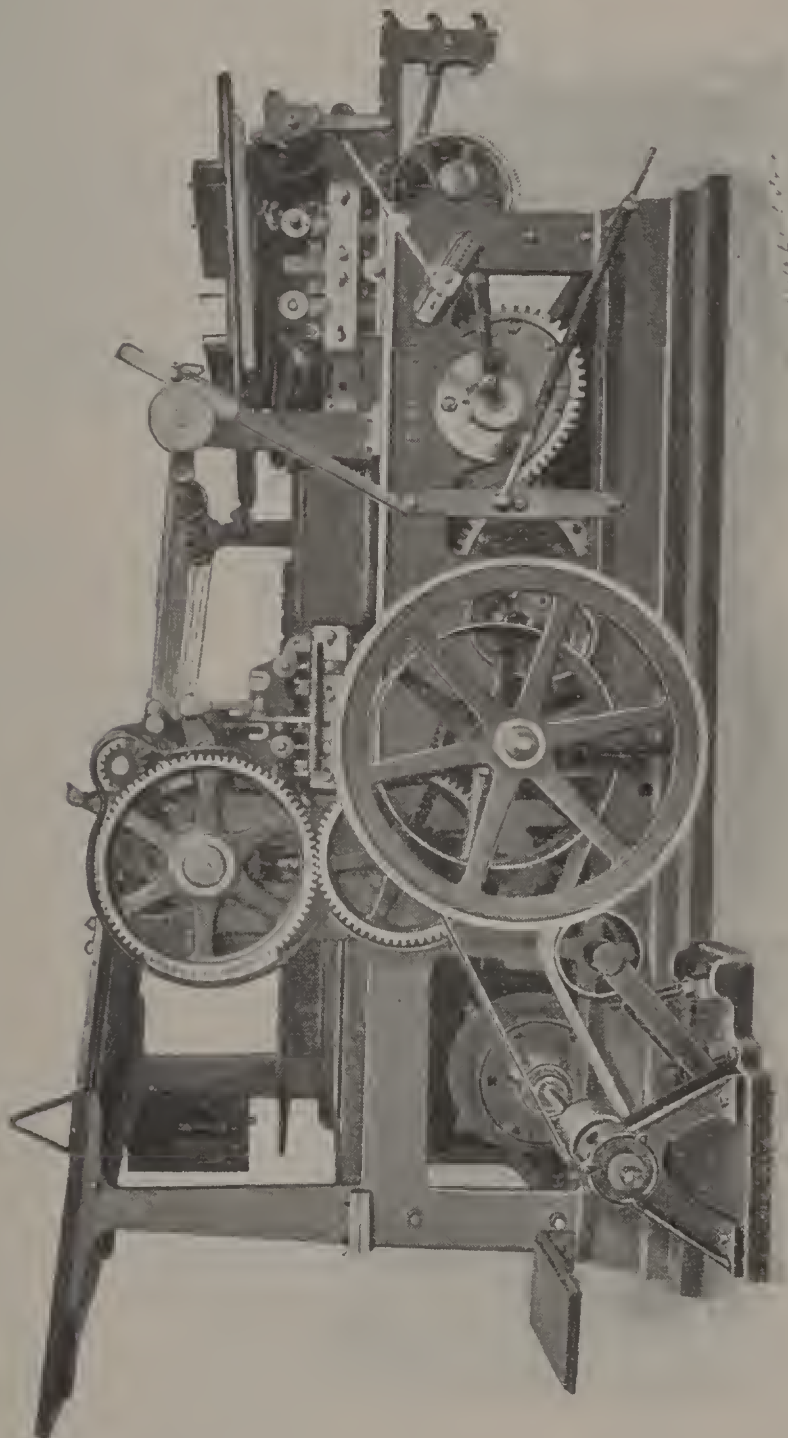


Fig. 260. — Sprague Round Type Motor, Belted to Printing Press.

detriment, shunt motors where change in load must not cause appreciable change in speed, and com-

pound motors for special cases, where the essential characteristics of shunt and series motors must be combined.

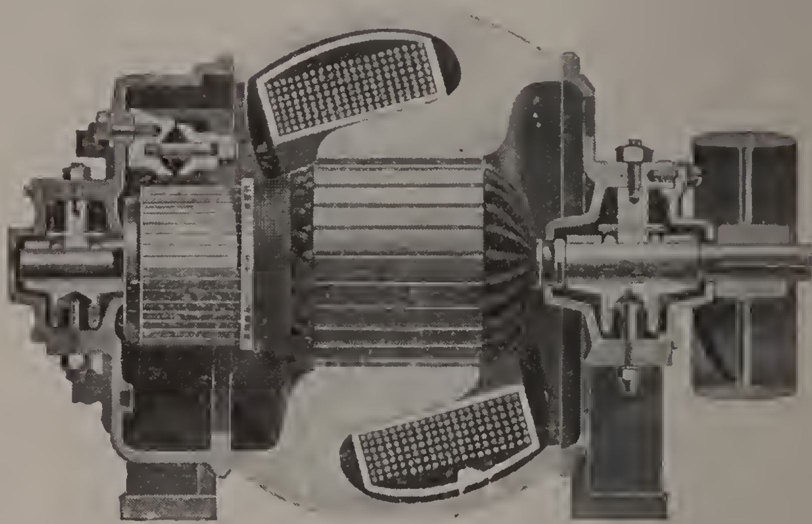


FIG. 261. — SPRAGUE ROUND TYPE MOTOR, SECTIONAL VIEW

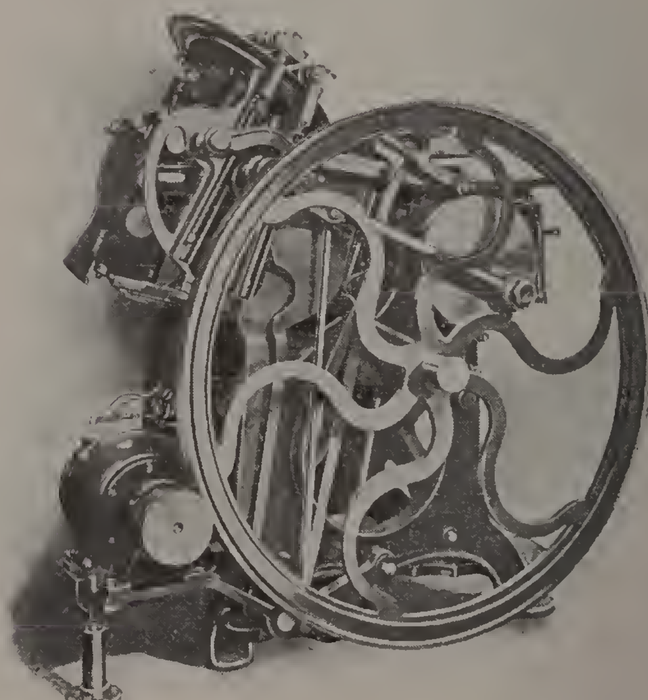


FIG. 262. — SPRAGUE ROUND TYPE MOTOR, OPERATING JOB PRESS BY FRICTION DRIVE.

Series motors are not at all suited to many uses admirably adapted to shunt motors, or *vice versa*. To illustrate: A shunt winding on a railway motor would mean abnormally large motors and heavy currents to get necessary starting torques. Again, on a machine tool, such as a boring mill, a series-wound or heavily-compounded motor would cause disastrous results. On boring out a field frame, for example, the tool would cut during only part of the revolution, as from *A* to *B* and *C* to *D* in Fig. 263. When cutting, the motor would be loaded and run at a certain adjusted speed. As the tool leaves the

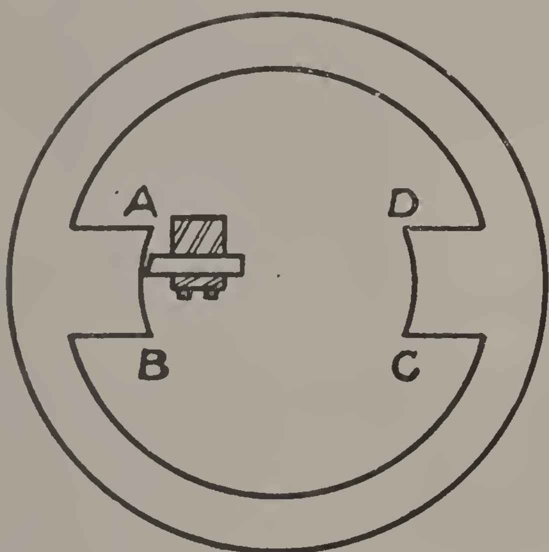


Fig. 263. — Boring Out a Field Frame.

pole face, the motor would speed up and the tool would hit the other face at high speed and either break or dig into the metal.

For variable speed work, the direct-current shunt-wound motor stands supreme. When specially designed for the purpose, with commutating poles, it is both light and cheap. This motor gives a smooth scale of speeds — not long steps from lowest to highest.

Speed may be adjusted in two ways: First, the motor may be slowed down by cutting resistance into the armature circuit. This, however, is very

wasteful, as for instance if we wish to run the motor at half speed we must use up half the voltage in the resistance. Also the resistance must be heavy and cumbersome, as it carries the full armature current. Secondly, the speed is increased by weakening the field. Resistance is cut into the field circuit. No energy is lost, as the current in the field-windings

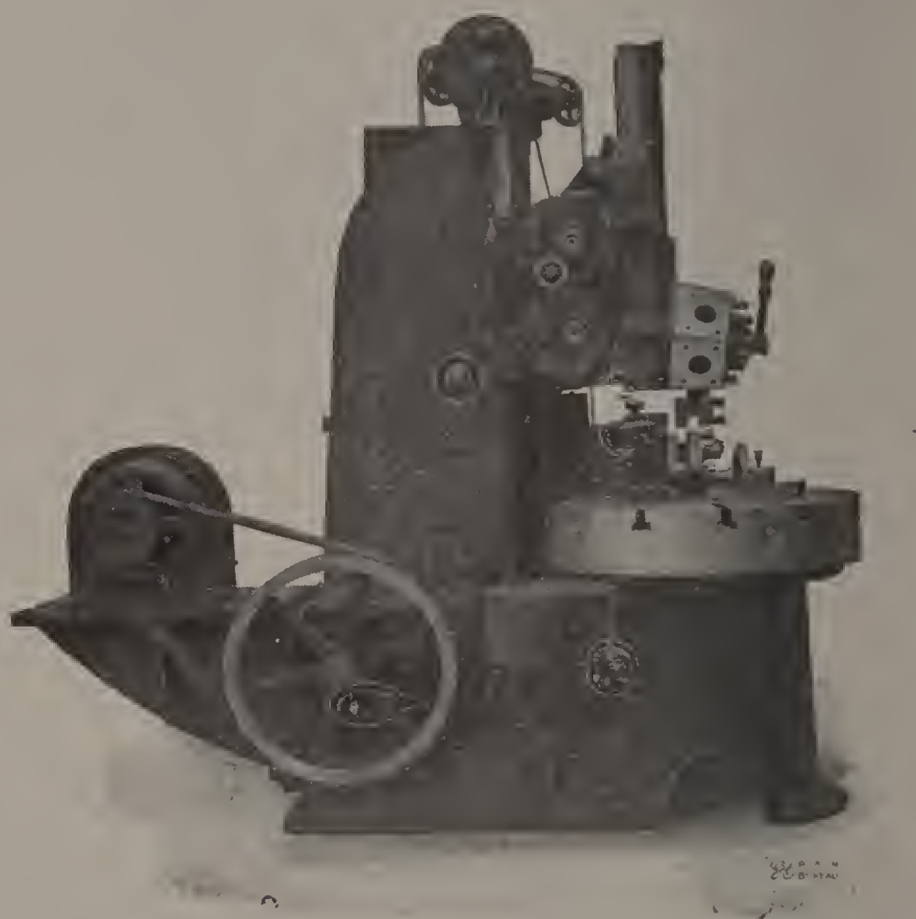


FIG. 264. — BORING MILL, OPERATED BY GENERAL ELECTRIC VARIABLE SPEED SHUNT MOTOR.

represents a dead loss of about 2% or 3% in any case, and as this current is reduced, the per cent. is still smaller. Sometimes a combination of the two methods is used, but in such cases the speeds brought under armature control should be as few as possible.

There are also one or two notable instances of satisfactory mechanical means for obtaining speed

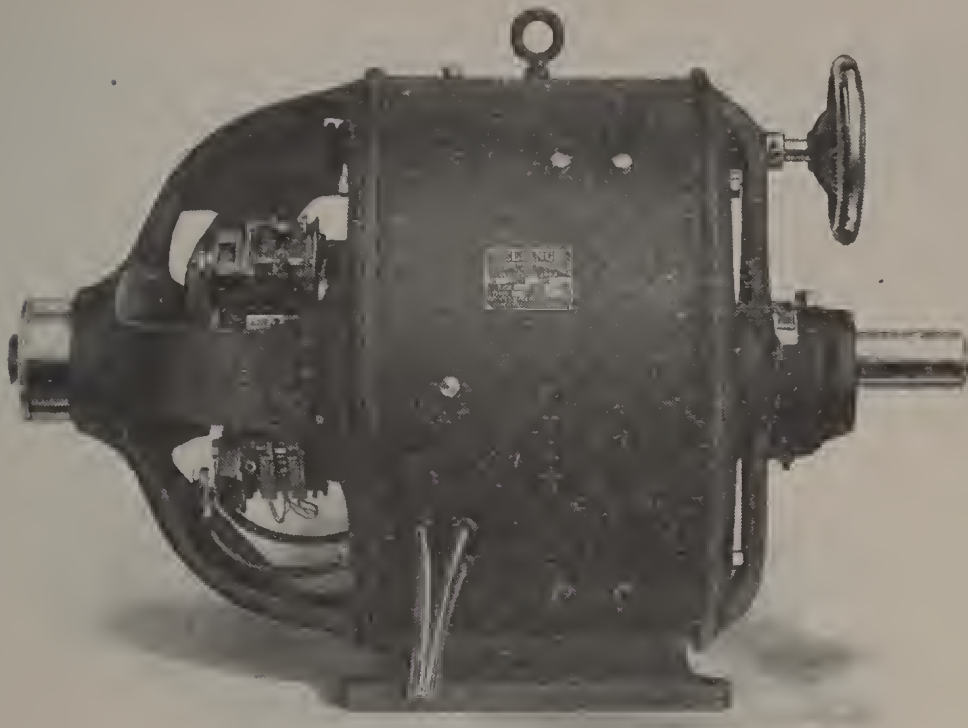


FIG. 265. — RELIANCE ADJUSTABLE SPEED MOTOR.

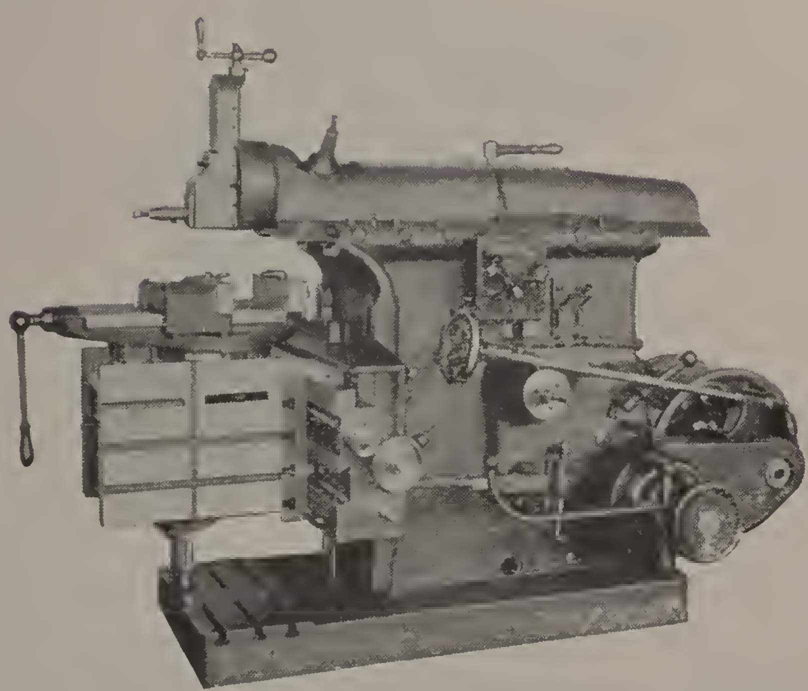


FIG. 266. — SHAPER, DRIVEN BY RELIANCE ADJUSTABLE SPEED MOTOR.

variation, such as in the motors made by the Reliance Engineering Works. There, the armature is conical in shape and is pushed in and out by turning a hand-wheel. The air gap is varied accordingly, changing the reluctance of magnetic circuit and effective strength of field.

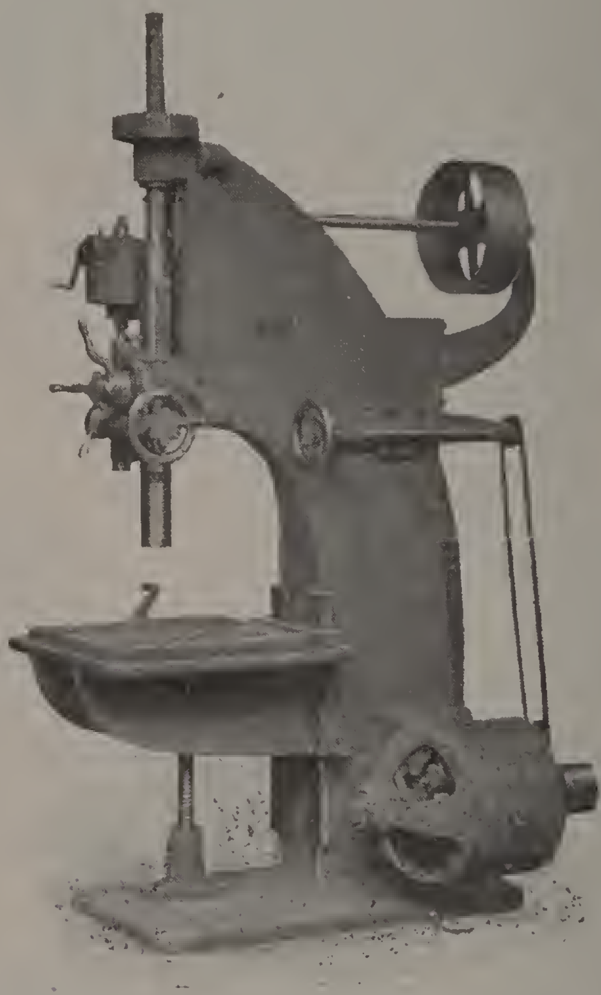


Fig. 267. — Drill Press, Driven by Reliance Adjustable Speed Motor. Speed Control Convenient to Operator.

With the introduction of motor drive into almost every industry, frequently a middle course is pursued by dividing the factory into sections, each section being driven by one large motor. This method, although not entirely eliminating overhead shafts and belts, combines many of the im-

portant advantages of individual-motor drive with lowered first cost — the one motor replacing several smaller ones.

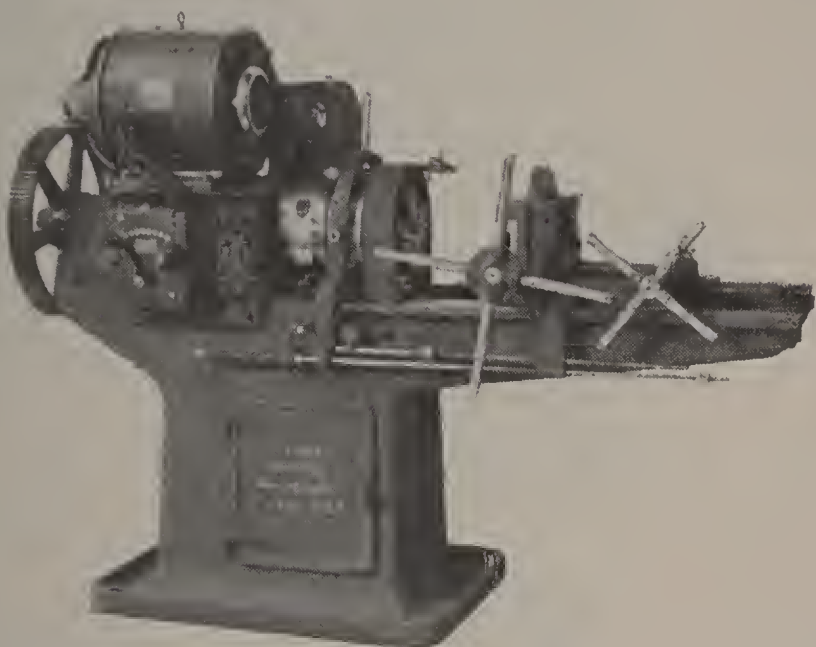


FIG. 268. — BOLT CUTTER, DRIVEN BY RELIANCE ADJUSTABLE SPEED MOTOR.

Below is given a list of the more important applications, with the type of motor best adapted for each use.

DIRECT-CURRENT SERIES MOTORS.

Electric Locomotive
Street Railway
Crane
Hoist and Derrick
Battleship, Elevating Guns and Turning Turrets, Hoists, Compartment Doors, etc.
Automobile
Air Compressor
Blower and Exhaust Fan
Coal Pick
Turn Table
Lifting Bridge
Rock Breaker
Gate Valve
Ceiling Fan
Launch
Church Organ Blower
Vacuum Cleaner
Forge Blower

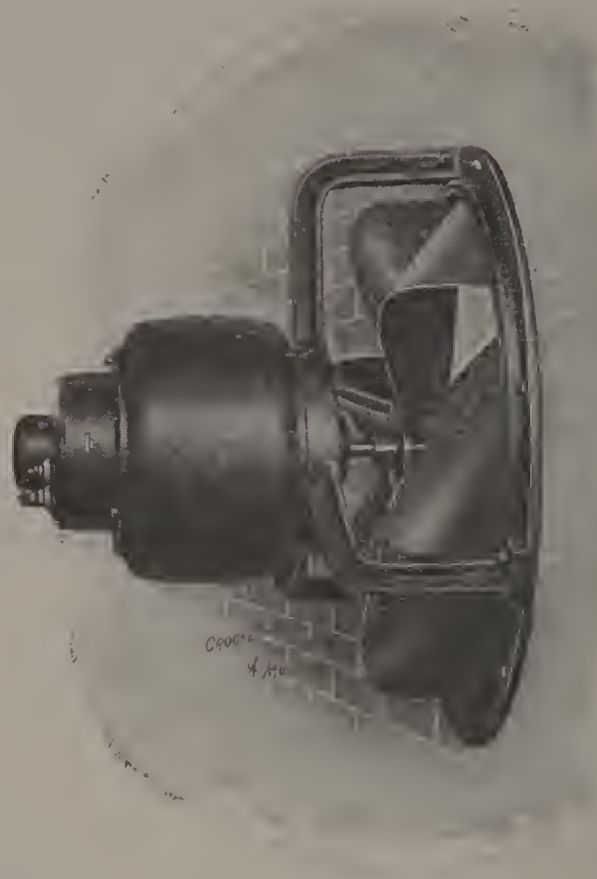


Fig. 269. — Exhaust Fan, Direct-Connected to Crocker-Wheeler Series Motor.

Fig. 270. — Pipe-Threading Machine, Geared to Crocker-Wheeler Compound Motor.

DIRECT-CURRENT COMPOUND MOTORS.*

Power Shear	Conveyor
Motor Generator Set	Portable Drill
Balancer Set	Ore Crusher
Punch Press	Pipe Threader
Drop Forge	Rolling Mill
Tumbling Barrel	Printing Press
Concrete Mixer	Gate Valve
Bread Mixer	Sewing Machine
Elevator	

FIG. 271. — ICE CREAM FREEZER, GEARED TO CROCKER-WHEELER SHUNT MOTOR.

FIG. 272. — GENERAL ELECTRIC PORTABLE BREAST DRILL.

*Compound field about 20% to 25% of total field, except in special cases.

DIRECT-CURRENT SHUNT MOTORS.

Lathe
Drill Press
Slotter
Shaper
Boring Mill
Milling Machine
Rivetting Machine
Gear Cutter
Moulding Machine
Planer
Laundry Machinery
Oil Switch
Band Saw
Buzz Saw
Jig Saw
Swing Saw
Automatic Stoker
Cold Steel Saw
Ice Cream Freezer
Exhaust Fan, Adjustable Speed
Shoe Machinery
Leather Machinery
Printing Press
Linotype
Folding Machine
Bending Machine
Brick Machine
Oil Press
Lawn Mower
Can Making Machine
Track Drill
Bottle Washer
Bottle Corker
Bottle Labeler
Grinder
Buffer
Coffee Grinder
Beef Cutter
Cloth Cutter
Centrifugal Pump
Cotton Mill Machinery
Flour Mill Machinery
Feed Pump
Tool Grinder
Farm Machinery
Pianola
Electric Clippers
Abbatoir Apparatus
Dentist Drill
Massage Vibrator

INDUCTION MOTOR,
Special Design with Armature Control.

Electric Locomotive
Crane
Hoist
Air Compressor

INDUCTION MOTOR,
Squirrel-Cage Type.

For all cases listed under direct-current shunt motors, except where adjustable speeds are desired; and, specially designed to give added torque, for those listed under compound motors.

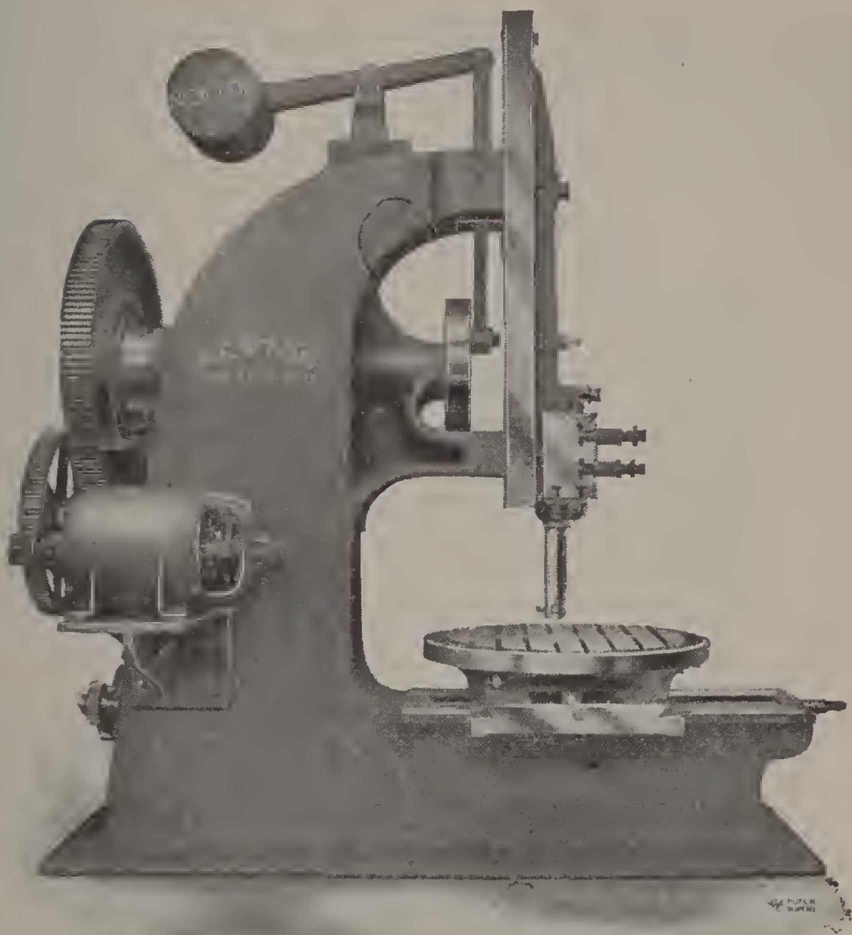


FIG. 273. — GENERAL ELECTRIC VARIABLE SPEED TYPE CR MOTOR, GEARED TO NEWTON SLOTTER.

FIG. 274. — SPRAGUE ROUND TYPE MOTOR, MOUNTED IN PEDESTAL OF SAW TABLE.

To determine the size of motor to use with a given machine, the best method is to make an actual test with the machine doing the maximum work it will be called upon to do. However, as it is not always practicable to make a test, resort must be

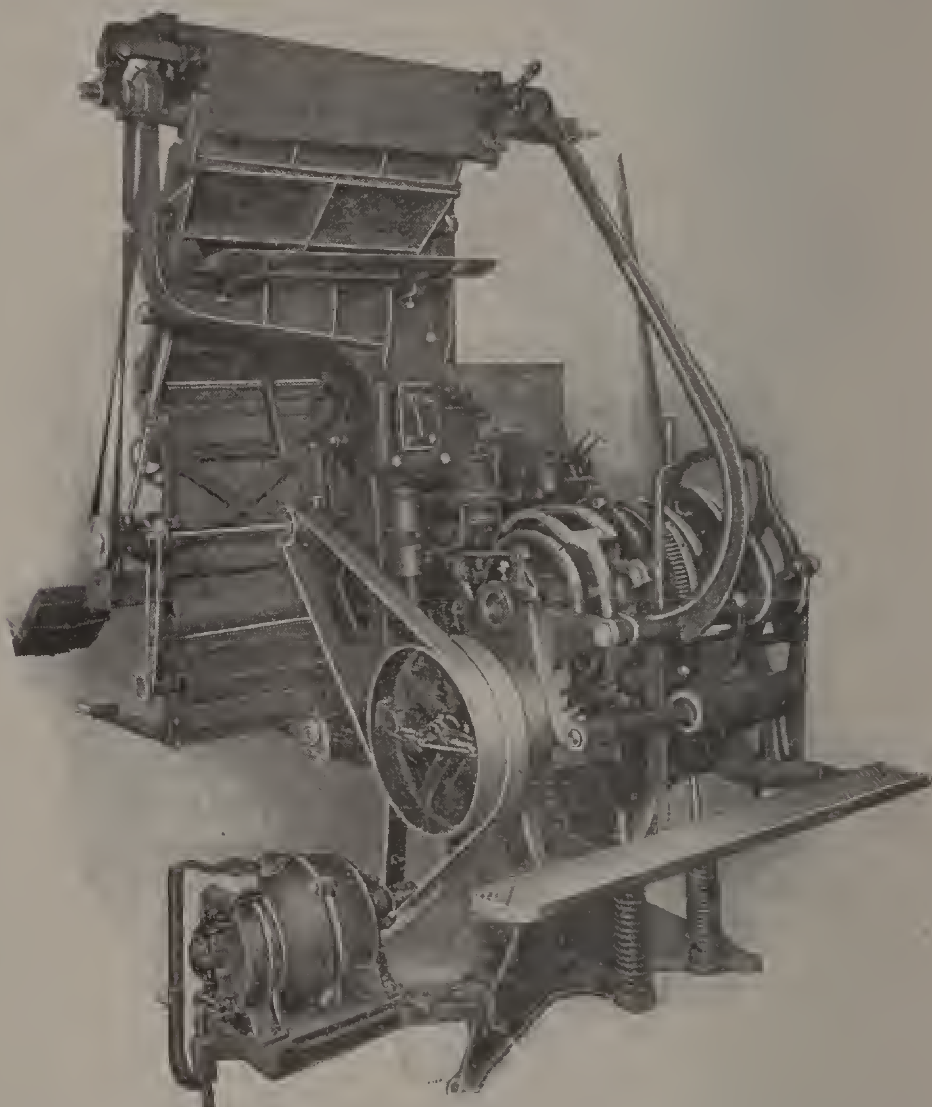


Fig. 275. — Sprague Round Type Motor, Belted to Linotype (Type-Setting) Machine.

had to tests recorded under average conditions of service. Practical experience, together with good common sense, will aid more than any hard and fast rule in predetermining the size motor to use in any special case, but the following list, giving size of

motors used in actual installations under average conditions, will be found useful as a basis of reference.

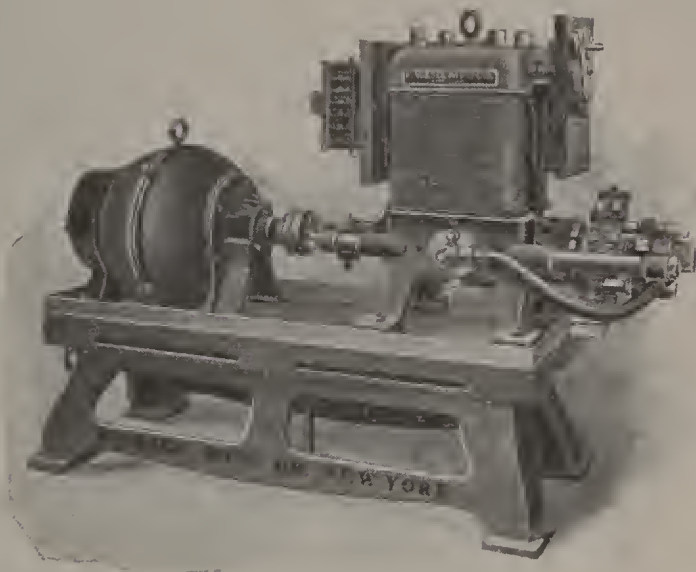


Fig. 276. — Sprague Round Type Motor, Direct-Connected to Electrotyping Dynamo. Special Example of Motor-Generator Set.

Machine Tools.

Machine	H.P. of Motor
72-in. driving-wheel lathe	5
48-in. lathe	5
36-in. lathe	4
24-in. lathe	3
16-in. tool-room lathe	2
60-in. x 60-in. x 25-ft. Pond planer	15
36-in. x 36-in. x 10-ft. Pond planer	5
18-in. Cincinnati D.H. shaper	3
18-in. Newton slotter	$7\frac{1}{2}$
14-in. Newton slotter	5
5-ft. radial drill	5
40-in. vertical drill	2
4-spindle gang drill	$7\frac{1}{2}$
10-ft. Pond boring mill	20
51-in. Baush boring mill	$7\frac{1}{2}$
No. 4 Newton duplex milling machine	10
No. 1 Acme bolt cutter	$7\frac{1}{2}$

Machine	H.P. of Motor
No. 5 oscillating grinder	25
No. 2 oscillating grinder and twist drill grinder	5
Car wheel press	10

Fig. 277. — Sprague Round Type Vertical Motor, Belted to Routing Machine.

Fig. 278. — Grinding Wheels on Shaft of General Electric Induction Motor.

Sawmill and Woodworking Machinery.

Machine	H.P. of Motor
Automatic cut-off saw	10
38-in. band resaw	8

Machine	H.P. of Motor
Automatic car gainer	15
Buzz planer	$7\frac{1}{2}$
Planer and matcher	25
Double surfacer	$17\frac{1}{2}$
Four-sided timber planer	45
Rip saw	15
Scroll saw	2
Tenoning machine	5
Hollow chisel mortiser	4
Universal saw bench	5

FIG. 279. — SAW ON SHAFT OF GENERAL ELECTRIC TYPE CQ MOTOR.

BLACKSMITH SHOP MACHINERY.

Machine	H.P. of Motor
Bolt header	5
Bolt shears	5
Bradley hammer	5
Forge blower	15

To bring home the relative cheapness of electric power, the following list has been compiled, showing what a nickel's-worth of power at 10c. per K.W.-hour will do:

Light a small room 75 minutes a night for a week.
Operate a 12-inch fan for 7½ hours.
Run a sewing machine for 15 hours.
Keep a 6-pound electric flat-iron hot for 75 minutes.
Boil 10 quarts of water.
Run a massage machine for nearly 20 hours.
Run an electric pianola for 5 hours.
Pump 2,500 gallons of water 50 feet high.
Raise 50 tons 12 feet high with an electric crane.
Raise a large passenger elevator eight stories three times.
Heat an electric curling iron once a day for two months.
Vulcanize four large patches on an automobile tire.
Burn an ordinary carbon-filament lamp giving 16-candle power for 9 hours.
Burn an 80-watt tungsten lamp giving 64-candle power for 6¼ hours.
Light a single glower Nernst lamp giving 85-candle power for 4½ hours.
Burn an enclosed arc lamp giving 370 mean hemispherical candle power for 70 minutes.
Light a 50-inch Cooper-Hewitt Mercury Vapor tube giving 500-candle power, for 80 minutes.

CHAPTER XXVII

OUTPUT

Limitations — Efficiency — Tests — Fahrenheit and Centigrade Thermometers — Ratings — Guarantees.

One would naturally suppose that the larger a machine, the greater its capacity. While this is true in a general way, yet it is not universally the case. For example, we might have two generators, apparently the same size and weight, one of which would easily handle a load of 500 K.W. and the other would be dangerously overloaded at 200 or 250 K.W.

Aside, then, from the size, there are several other conditions which limit the output of an electrical machine. As one illustration, suppose we could safely obtain 50 amperes at 110 volts or 5.5 K.W. from a given dynamo running at 1000 R.P.M. If we could increase the speed to 2000 R.P.M. the voltage would be doubled. We could still take 50 amperes of current from the machine with equal safety, but in this case the power would be 50×220 or 11.0 K.W. From this one illustration it is apparent why slow-speed machines are so much heavier and more expensive than those of the same rated output designed for high speeds.

The factors which limit the output of a given machine are:

Voltage
Current
Regulation

Strength of those parts which transmit the power mechanically, and

Available Power of the prime mover which is driving the machine, if a generator.

These last two are self-evident, so we will proceed to study the conditions on which the other factors — voltage, current, and regulation — depend.

The greatest voltage which may be generated in a machine is limited by the strength of insulation of the windings, the speed, and strength of magnetic field. Because of that magnetic property of iron known as saturation (see Chapter XX) the current required in field windings to increase the strength of field above a certain point is disproportionately large. Also the amount of current that can be sent through these windings is limited, both by the resistance, and by the heat which large currents would produce in them.

To get the greatest output from a given amount of material, the speed should be as high as possible. But it must not be so great as to destroy the commutator or armature by centrifugal force, or to cause any of the commutator bars to work loose and rise above the others; nor may it be so great as to overheat the bearings. If an alternating-current machine, the speed is fixed and determined by the frequency of the current it must supply.

The amount of current which may be taken from a machine is dependent upon the heating of the windings, and in direct-current machines, upon commutation. If a wire carries more than a certain amount of current for any considerable time, it will become so hot as to burn the insulation. Of course this amount depends on the kind of insulation and also on the location of wire. If out of doors, fanned by the cool breezes, obviously it can carry more current than if in doors, under a moulding or in a conduit. As armature windings are subjected to very forcible ventilation, due to the drafts of air

set up by rotation of the armature, the conductors may be allowed to carry more than wires of the same size under other conditions.

Besides that generated in the winding, heat is produced in the iron core or body of the armature by **eddy currents,** which can not be entirely eliminated even though the core is built up of thin laminations, and by **hysteresis,** a sort of magnetic friction in the iron caused by the rapid reversals of magnetism. The heat produced in the armature in these ways, must not be greater than can be dissipated before the temperature exceeds certain safe limits.

The commutator also tends to overheat, when the load becomes excessive, because there is a certain amount of resistance in the contact between commutator and brush. The energy consumed in this resistance appears as heat in the commutator. Again, heavy currents in the armature coils are more difficult to commutate, producing an excessive amount of sparking, which also heats the commutator, as well as burning it and making it rough and uneven.

The regulation of a generator is the variation in voltage from no load to the rated full load, expressed as a per cent. of full-load voltage. To understand why the regulation should limit the output of a generator, we must remember that for the usual commercial purposes, it is essential that the voltage should be very nearly constant, no matter what the load. You have often been on a car, when that and possibly several others at the same time were climbing a steep hill. The generators and feeder system under those conditions were so heavily overloaded that the car lights were noticeably dimmed. For railway motors such a reduction in the voltage is not important, but in a lighting system it would be intolerable.

The regulation of a motor is its variation in speed from no load to full load, in per cent. of full-

load speed. The following discussion of the regulation of a motor will point out to us some of the factors which affect regulation in any dynamo, and then we will be prepared to note how the rated output of a machine is limited by the regulation. This discussion refers to an ordinary shunt motor on a constant potential circuit, with the field connected directly across the line.

Under no load, the motor is, of course, running free, and the armature current and torque are small. The drop in voltage due to armature resistance will be small and the counter electromotive force high, almost equaling the line voltage. It must be remembered that the sum of the resistance drop in the armature and the counter electromotive force is the line voltage, and that the torque is proportional to the armature current and field strength.

As the load is put on, the torque is insufficient, and the speed drops, thereby decreasing the counter electromotive force and allowing the armature current to increase until the resistance drop in armature becomes the difference between the line voltage and the counter electromotive force.

It will be readily seen from the following example that a small decrease of speed gives a large increase in armature current and torque. Therefore, the regulation of a shunt motor is, as a rule, good.

For illustration, take a shunt motor with an armature resistance of .15 ohms connected to a 115-volt line. When running free, the armature current is 5 amperes, and therefore the resistance drop in armature is .75 volts, and the counter electromotive force is 114.25 volts.

If the full-load current is 40 amperes, the resistance drop will be 6 volts and the counter electromotive force will be 109 volts.

With a no-load speed of 1500 revolutions per minute, it is apparent that the speed under full load is approximately:

$$1500 \times \frac{109}{114.25} = 1430 \text{ revolutions per minute.}$$

The example is merely to make clearer this drop in speed as the load comes on, and if applied to a practical case, other quantities, such as armature reaction, and the drop due to contact resistance of brushes and commutator, would still further affect the speed. At heavy loads, armature reaction plays a very important part.

In the case of a shunt generator, these same causes produce a reduction in the voltage. As the voltage decreases, the field current is reduced. This causes a still further reduction in the voltage. If the load on a shunt generator were increased to extremely large values, and other parts did not first give way or burn out, the effect of this would be that finally the machine would cease to generate. Characteristic curves of a shunt generator droop very rapidly beyond 25% or 50% overload.

A well-designed machine should reach the limits of satisfactory operation in each of these particulars at about the same load. That is, when the temperature rise in armature reaches the value specified in the guarantee, that in the commutator should be at or near its specified limit; loss of speed or voltage should be no greater than permissible in the service to which machine is to be applied; efficiency should be at or near its maximum; speed should be as high as consistent with other requirements; and field magnets should be worked at or near their points of saturation. Such conditions insure the greatest output for the amount of material used.

Electrical machines are subjected to tests for several purposes. The usual tests applied are those for determining the efficiency and other data for characteristic curves, for proving that there are no serious defects in the insulation, and for determin-

ing the rise in temperature of various parts of the machine under varying conditions of load.

The efficiency of any machine is the ratio of the output to the energy supplied. In other words, the greater the amount of losses in a machine, the less will be its efficiency. These losses can be divided under two headings:

1. Stray power, consisting of losses due to bearing friction, friction of brushes, if any, on commutator or slip rings, windage, or air resistance to rotation due to the fanning action of rotating elements, and lastly, core losses, from eddy currents and hysteresis in the iron.

2. Electrical losses, or RI^2 loss in armature and field windings, brushes, etc.

Efficiency tests may be made in several ways. We may run the machine as a motor and measure the amount of electrical energy supplied to it, at the same time determining its power output by means of a "prony brake," or we may use the so-called motor-generator method, or thirdly the stray-power method.

Insulation tests are applied for the purpose of discovering any weak points in the insulation before the apparatus is sent out of the shops. While the ohmic resistance should be large, it is a less important point than the dielectric strength or resistance to rupture at high voltage.

High potential should be applied from each winding to all other windings, and then from each winding to the frame. In all ordinary cases, small motors for operation on circuits of 800 volts or less, and in sizes up to and including ten horsepower, a test voltage of 1500 is sufficient, while on fifteen horsepower and larger, 2000 volts is used.

The breaking down of the insulation of a motor may be attended with results more or less surprising, of which the following incident will serve as an example. Mounted on an insulated stand in a

dentist's office, was a small two-phase induction motor, used in connection with a dental drill. There were four incoming lines to the motor, two for each phase, and where they entered the building, one of the lines to phase *A* was grounded. Now it so happened that at the motor the other side of the same phase had given way, allowing the winding at this point to make contact with the motor frame and thus through the bearings and flexible shaft to the drill. If, while the drill was in operation, the patient touched the metal cuspidor, preparatory to expectorating, the sensations received were hardly pleasing, and caused doubt as to the real meaning of the signs in front, advertising painless treatment.

Needless to say there were several excited patients and a much mystified dentist before the real cause of the trouble was revealed by a voltmeter being connected from the point of the drill to the metal cuspidor, which was grounded by the piping.

In the case of a transformer, two tests are made. In the first, a voltage is applied from secondary to all parts (frame and other winding), and then a voltage is applied from the primary to all parts. How much this voltage should be, depends on the circumstances and the rated voltage of the transformer.

Recommendations from the Standardizations Rules of the American Institute of Electrical Engineers are that this voltage should be 10,000 volts for transformers with primary pressures of from 550 to 5,000 volts, and with their secondaries connected directly to consumption circuits.

Second test consists in applying to one of the windings, a voltage two or three times normal. The other winding is left open-circuited. This of course makes two or three times normal voltage between all the different layers and turns of each winding.

Electrical machines are usually sold under a

guarantee that the various parts will not rise more than a specified number of degrees above the temperature of the air, after running under a given load for a certain time. To make sure that these requirements are fulfilled, the machine is subjected to various loads for the time called for in the guarantee, and at the end of that time, the temperatures of various parts are measured and recorded. The temperatures of the coils are best determined by measuring their resistances at the start of the run and at its finish. As copper increases in resistance $\frac{4}{10}$ of 1% for each degree Centigrade rise in temperature, it is seen that the average temperature of interior of the coil may be determined by this method, which is much better than to measure the temperature at the outside of the coil with a thermometer. However, this method cannot be applied to such parts as the commutator or bearings, and for these parts thermometers must be used. After the machine has stopped, the thermometer bulb is laid against the commutator, covered with a small piece of clean, dry felt, and held until it reaches a constant temperature. Sometimes, especially in such places as on the bearings or other stationary parts of the machine, the thermometer bulb is attached to the machine while running, by a wad of putty.

In this connection we note that there are two kinds of thermometers in use in this country: the Fahrenheit, which is in common use, and the Centigrade, which is more largely used in engineering and scientific work. 5° on the Centigrade thermometer is equal to 9° on the Fahrenheit. The Centigrade thermometer has its zero point at the temperature of melting ice, while the temperature of steam or boiling water is 100° on this scale. These points on the Fahrenheit thermometer are 32° and 212° respectively. By keeping these figures in mind one can easily reduce temperatures given on one scale to those indicated by the other.

The following is an extract from the report of Standardizations Committee of American Institute of Electrical Engineers, on the allowable temperature rise and overload capacities of electrical apparatus, as affecting the ratings and guarantees.

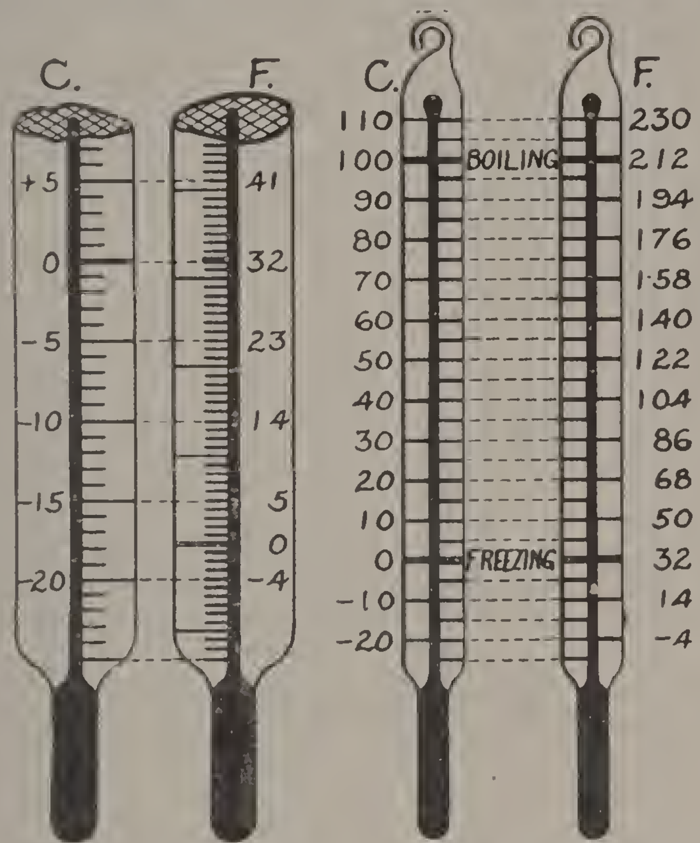


FIG. 280. — FAHRENHEIT AND CENTIGRADE THERMOMETERS COMPARED.

It is recommended that the following maximum values of temperature elevation should not be exceeded after continuous operation at full load:

Commutating machines, rectifying machines and synchronous machines.

> Field and armature, by resistance, 50° C.
> Commutator and collector rings and brushes, by thermometer, 55° C.
> Bearings and other parts of machine, by thermometer, 40° C.

Rotary induction apparatus.

> Electric circuits, 50° C., by resistance.
> Bearings and other parts of machine, 40° C., by thermometer.

In squirrel-cage or short-circuited armatures, 55° C., by thermometer, may be allowed.

Transformers for continuous service — electric circuits by resistance, 50° C., other parts by thermometer, 40° C., under conditions of normal ventilation.

Reactors, induction and magneto-regulators — electric circuits by resistance, 50° C., other parts by thermometer, 40° C.

Where a thermometer, applied to a coil or winding, indicates a higher temperature elevation than that shown by resistance measurement, the thermometer indication should be accepted. In using the thermometer, care should be taken so to protect its bulb as to prevent radiation from it, and, at the same time, not to interfere seriously with the normal radiation from the part to which it is applied.

In the case of apparatus intended for intermittent service, except railway motors, the temperature elevation which is attained at the end of the period corresponding to the term of full load, should not exceed 50° C., by resistance in electric circuits. In the case of transformers intended for intermittent service, or not operating continuously at full load, but continuously in circuit, as in the ordinary case of lighting transformers, the temperature elevation above the surrounding air temperature should not exceed 50° C. by resistance in electric circuits and 40° C. by thermometer in other parts, after the period corresponding to the term of full load. In this instance, the test load should not be applied until the transformer has been in circuit for a sufficient time to attain the temperature elevation due to core loss. With transformers for commercial lighting, the duration of the full-load test may be taken as three hours, unless otherwise specified. In the case of railway, crane, and elevator motors, the conditions of service are necessarily so varied that no specific period corresponding to the full-term load can be stated.

The commercial rating of a railway motor should be the H.P. output giving 75° C. rise of temperature above a room temperature of 25° C., after one hour's continuous run at 500 volts terminal pressure, on a stand, with the motor covers removed.

Overload Capacities.

All guarantees on heating, regulation, sparking, etc., should apply to the rated load, except where expressly specified otherwise, and in alternating-current apparatus to power factor = 1.

All apparatus should be able to carry the specified overload without self-destruction by heating, sparking, mechanical weakness, etc., and with an increase in temperature elevation not exceeding 15° C. above those specified for full loads,

the overload being applied after the apparatus has acquired the temperature corresponding to full-load continuous operation.

Overload guarantees should refer to normal conditions of operation regarding speed, frequency, voltage, etc., and to power factor = unity.

The following overload capacities are recommended:

1st. In direct-current generators and alternating-current generators, 25 per cent. for two hours.

2d. In direct-current motors, induction motors and synchronous motors, not including railway motors and other apparatus intended for intermittent service, 25 per cent. for two hours, and 50 per cent. for one minute, for momentary overload capacity.

3d. Synchronous converters. 50 per cent. for one-half hour.

4th. Transformers. 25 per cent. for two hours. Except in transformers connected to apparatus for which a different overload is guaranteed, in which case the same guarantees shall apply for the transformers as for the apparatus connected thereto.

5th. Exciters of alternators and other synchronous machines, 10 per cent. more overload than is required for the excitation of the synchronous machine at its guaranteed overload, and for the same period of time.

7th. All exciters of alternating-current single-phase or polyphase generators, should be able to give, at constant speed, sufficient voltage to excite the alternator, at the rated speed, to the full-load terminal voltage, at the rated output in kilovolt amperes and with 50 per cent. power factor.

CHAPTER XXVIII

WIRES

Copper, Aluminum, etc. — Weight — Resistance — Current-Carrying Capacity — The Wire Table.

In buying and ordering wires for work of any importance, such as for transmission lines, it is necessary to decide what size and kind of wire would be satisfactory. This brings up the question of how wires are measured. The different sizes of wire could be specified by naming their diameters, as, for instance, a wire three-tenths (.3) or twenty-three one-hundredths (.23) or fifty-five one-thousandths (.055) of an inch in diameter, these measurements being taken with an ordinary micrometer.

The unit most commonly used, however, in measuring wires, is the mil, this being a short name for a thousandth of an inch. Thus, if we say a certain wire is 18 mils in diameter, we mean that it would measure (.018″) eighteen thousandths of an inch.

In measuring the cross-sectional area of a round wire, we use a unit called the circular mil, this being the area of a circle whose diameter is one mil. If we have a square whose sides measure 2 inches, we find its area by multiplying 2×2. That is, the square contains 4 square inches. If its sides were 2 mils, the area would be $2 \times 2 = 4$ square mils, or .000004 square inch. In a similar way, a circle whose diameter is 2 mils, would have an area of $2 \times 2 = 4$ circular mils, written 4 CM*.

* The area in square mils is equal to that in circular mils multiplied by $\frac{\pi}{4}$ or .7854, while the area in square

For convenience, the size of wire is commonly specified in this country by a certain gauge number instead of by the diameter in inches or in mils. The larger sizes of cable, however, are listed as having a cross-section of so many circular mils. In the United States the **Brown & Sharpe (B. & S.) Gauge** is in almost universal use. Thus a No. 18 wire is understood to mean No. 18 B. & S. Gauge, which is 40 mils in diameter. In England, the gauge most universally used is the **"New British Standard Gauge."**

For the convenience of those using wires very much and constantly in need of information regarding them, wire tables have been prepared. These are merely a compilation of data and information about wires of different materials giving the diameter in mils, cross-sectional area in circular mils, weight and resistance per 1,000 feet of the various sizes. Most of the data is calculated from the formulas which may be found later in this chapter.

In the United States and Great Britain, the length of a wire is measured by the inch, foot or mile. In France and other countries where the metric system of measuring is employed, the length of a wire is measured by centimeters, meters and kilometers. The metric system of measurements is much simpler and has other advantages over the system we use in this country. It has not been extensively adopted in every-day work in the United States, except in our system of money, although widely used in scientific work. Tables are given in the Appendix showing values of the units used in the metric system in terms of those used in the English or American system.

inches equals that in circular mils times .0000007854. Possibly the following table will be useful:

1 square inch = 1,000,000 square mils.
1 square inch = 1,275,000 circular mils.
1 circular mil = .7854 square mil.
1 circular mil = .0000007854 square inch.

A mil-foot is a length of wire one foot long and one mil or one-thousandth of an inch in diameter. One mil-foot of copper wire weighs approximately .00000303 pound, and 1000 ft. of wire, one mil in diameter, would weigh .00303 pound. Aluminum

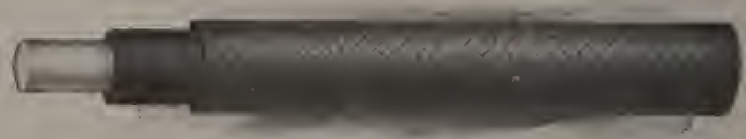


Fig. 281. — "Parac" Solid Rubber-Covered Wire.

wire weighs about .00000105 pound per mil-foot, or .00105 pound per thousand mil-feet.

Knowing the weight of a wire 1000 feet long and 1 mil in diameter or 1 circular mil in area, we can calculate the weight of any wire by multiplying this weight, .00303 pound, by the area in circular mils. The result is the weight per 1000 feet. For copper wire, the formula is:

$$W = .00303\ D^2$$

Where W = weight per 1000 feet
D = diameter of wire in mils

or $$W = .00303\ A$$

where A = area of wire in circular mils.

Fig. 282. — "Parac" Stranded Rubber-Covered Conductor.

From this formula the weight of any amount of copper wire can be found, if the length in feet and

diameter in mils is known. For an example, No. 18 copper wire is 40 mils in diameter. 1000 feet would weigh $W = .00303 \times 40 \times 40 = 4.85$ pounds; 200 feet would weigh $4.85 \times .200 = .97$ pound.

The resistance of one mil-foot of copper wire of ordinary commercial purity and at a temperature

Fig. 283. — "Parac" Duplex Rubber-Covered Wires, for Use in Conduit, etc.

of about 25° C. or 75° F., is approximately 10.5 ohms, and this value can be used in preliminary calculations and where extreme accuracy is not essential.

Using this value, the resistance of a copper wire is

$$R = \frac{10.5\ L}{D^2}.$$

Where R = resistance of the wire
L = its length in feet
D = its diameter in mils

or
$$R = \frac{10.5\ L}{A}$$

where A = its area in circular mils.

Fig. 284. — "O.K." Solid Weatherproof.

To apply this formula, suppose it is desired to find the resistance of a No. 16 wire 1000 feet long.

The diameter is 51 mils, or the area is $51^2 = 2601$ circular mils. Substituting these figures in the formula

$$R = \frac{10.5 \times 1000}{2601} = 4.04 \text{ ohms.}$$

If greater accuracy is necessary, we must take

FIG. 285. — "O.K." SLOW-BURNING WEATHERPROOF, BLACK OUTSIDE.

into account the temperature of the wire, and use instead of 10.5, 9.57 times 1 plus the temperature in degrees Centigrade multiplied by .004 $(9.57 \times [1 + .004t])$. The reason for this is that metallic wires, such as copper or iron, expand when heated. The molecules or little particles of which the wire is composed push each other further apart as the temperature rises, causing the wire to expand and at the same time making it more difficult for the current to pass from molecule to molecule — in other

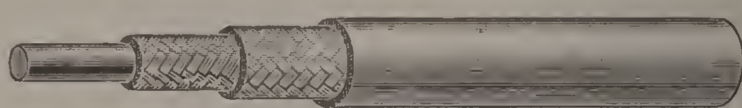


FIG. 286. — "O.K." SLOW-BURNING, WHITE OUTSIDE.

words, increasing the resistance. A thousand feet of No. 16 copper wire has a resistance of 4.04 ohms at 75° F. as compared with only 3.91 at 60° F.

Wires for electrical use may be made, according to the purpose for which they are intended, of copper, iron, steel, german silver, or any one of numerous

alloys of two or more metals, many of these alloys having special trade names such as Nichrome, Manganin, Climax, Superior, "Ia Ia," Nickeline, etc.

Copper is used most extensively for the transmission of current, and in the current-carrying parts of electrical apparatus where low resistance is desired. It has the lowest resistance of any metal except silver, and nearly as low as that. It is reasonably strong and at the same time pliable, easy to twist and join together.

Being lighter than copper for the same conductivity, aluminum is sometimes used, although it

Fig. 287. — Paper-Insulated and Lead-Covered Cable. G. E. Co.

Fig. 288. — Paper-Insulated, Lead-Covered Cable, with Jute and Asphalt Jacket. G. E. Co.

is very brittle and hard to handle, and although lighter it is larger in size than copper and more expensive to cover with insulation. Where only a small current is to be transmitted, as in telegraph work, iron wires are sometimes used. Their advantage is in strength and cost. The conductivity of iron is about $\frac{1}{6}$ that of copper, hence a copper wire of a given size can carry approximately six times as much current as an iron of the same size.

There are on the market several bimetallic wires, consisting of an iron wire in the center

surrounded by a copper cover. This gives the strength of the iron combined to a degree with the conducting properties of copper. Its higher initial expense offsets these advantages for most uses.

For use in rheostats or in other places where high resistance is desired, german silver or some other high-resistance alloy is used. For standards of resistance, which must be constant regardless of temperature conditions, a wire of manganin is often used, as this alloy between certain limits has almost

Fig. 289.—Paper-Insulated, Lead-Covered and Band-Steel Armored Cable, with Jute and Asphalt Jacket. General Electric Co.

Fig. 290.—Rubber-Insulated and Lead-Covered Cable. Four Conductors. General Electric Co.

no variation in resistance with changes in temperature.

In cases where the current is large, wire of sufficient cross-section must be used to prevent overheating, and to reduce the voltage as little as possible. In handling wires, stringing them on poles, etc., it is hard to handle a hard, stiff wire — being awkward to make joints and bends — consequently No. 0000 B. & S. gauge is the largest single or solid wire ordinarily used. After this point cables are used, consisting of a number of smaller wires stranded together.

To insulate wires from each other and prevent short-circuits or grounds and endangering lives, wires are covered with insulation. There are several kinds in use, the three most common being **Rubber Covered, Weatherproof,** and **Slow-Burning Weatherproof**; and for underground and submarine work, lead-covered cables are often used.

In rubber-covered wires, usually called R.C., the copper conductor is first tinned, and then covered with rubber, over which is placed a finishing layer of cotton braid, saturated with a weatherproof

Fig. 291. — Rubber-Insulated, Lead-Covered and Wire-Armored Cable. General Electric Co.

Fig. 292.—Paper-Insulated and Lead-Covered Cable, Three Conductors. General Electric Co.

compound. This protects the rubber insulation. Rubber-covered wires are used largely in indoor work.

In the weatherproof insulation, the bare wire is covered with three braids, which are then thoroughly impregnated with a black weatherproof compound. The outside is polished or rubbed smooth so as to make it shed water or snow more easily. This is known as triple-braided. Wires with this insulation are particularly applicable for exterior work.

Slow-burning weatherproof is suitable for indoor use in certain cases, and is required where a

large quantity of small wiring is bunched, as behind switchboards, or in wire shafts. Here rubber-covered wire would cause a large fire risk. It also has three braids, all of which are thoroughly soaked in a flame-proof compound and then polished.

CURRENT-CARRYING CAPACITY					
Solid Wires			Cables		
Size — Gauge No. B. & S.	Amperes Rubber Covered Insulation	Amperes Weather-proof Insulation	Size — Area Cir. Mils.	Amperes Rubber Covered Insulation	Amperes Weather-proof Insulation
18....	3	5	300,000	270	400
17....	4	6	400,000	330	500
16....	6	8	500,000	390	590
15....	8	10	600,000	450	680
14....	12	16	700,000	500	760
13....	14	19	800,000	550	840
12....	17	23	900,000	600	920
11....	21	27	1,000,000	650	1000
10....	24	32	1,100,000	690	1080
9....	29	39	1,200,000	730	1150
8....	33	46	1,300,000	770	1220
7....	39	56	1,400,000	810	1290
6....	45	65	1,500,000	850	1360
5....	54	77	1,600,000	890	1430
4....	65	92	1,700,000	930	1490
3....	76	110	1,800,000	970	1550
2....	90	131	1,900,000	1010	1610
			2,000,000	1050	1670
1....	107	156			
0....	127	185			
00....	150	220			
000....	177	262			
0000....	210	312			

Cables for submarine or underground work are lead-covered. In some cases the lead covering is protected by a layer of iron wires.

The more current a wire carries, the hotter it becomes. Now if the temperature of a conductor rises beyond a certain degree it will be hot enough

to cause a deterioration of the insulation — burning or charring it. Therefore, there is a certain current limit which should not be exceeded. This is called the current-carrying capacity of a wire, and in the accompanying wire tables the values of current given are those which the conductors will carry safely. It will be noticed that the current values are less for rubber-covered wire than for weatherproof, as rubber is more quickly affected by heat and the wires must not be allowed as high a temperature rise as with weatherproof.

It must be remembered that the heating effect varies as the square of current. That is, if the current is doubled the heating effect is four times as great.

The following table is convenient to find different sizes of wire which can be used in case the desired size is not at hand. For instance, if you wished to use a No. 0000 and had none at hand, 8 No. 6 wires would serve the same purpose.

Wires of Equivalent Cross Section.

0000	2– 0	4– 3	8– 6	16– 9	32–12	64–15
000	2– 1	4– 4	8– 7	16–10	32–13	64–16
00	2– 2	4– 5	8– 8	16–11	32–14	64–17
0	2– 3	4– 6	8– 9	16–12	32–15	64–18
1	2– 4	4– 7	8–10	16–13	32–16	
2	2– 5	4– 8	8–11	16–14	32–17	
3	2– 6	4– 9	8–12	16–15	32–18	
4	2– 7	4–10	8–13	16–16		
5	2– 8	4–11	8–14	16–17		
6	2– 9	4–12	8–15	16–18		
7	2–10	4–13	8–16			
8	2–11	4–14	8–17			
9	2–12	4–15	8–18			
10	2–13	4–16				
11	2–14	4–17				
12	2–15	4–18				
13	2–16	4–19				
14	2–17					
15	2–18					
16	2–19					

WIRE TABLE

Gauge No. B. & S.	Diameter Mils.	Area Circular Mils.	Ohms per 1000 Ft.	Lbs. per 1000 Ft. Bare	Lbs. per 1000 Ft. T. B. Weather-proof Insulation
18...	40	1,600	6.3880	4.92	16
17...	45	2,025	5.0660	6.20	
16...	51	2,601	4.0176	7.82	20
15...	57	3,249	3.1860	9.86	
14...	64	4,096	2.5266	12.44	26
13...	72	5,184	2.0037	15.68	
12...	81	6,561	1.5890	19.77	35
11...	91	8,281	1.2602	24.93	
10...	102	10,404	.99948	31.44	55
9...	114	12,996	.79242	39.65	
8...	128	16,384	.62849	49.99	78
7...	144	20,736	.49845	63.03	
6...	162	26,244	.39528	79.49	112
5...	182	33,124	.31346	100.23	145
4...	204	41,616	.24858	126.40	164
3...	229	52,441	.19714	159.38	210
2...	258	66,564	.15633	200.98	268
1...	289	83,521	.12398	253.43	306
0...	325	105,625	.09827	319.74	400
00...	365	133,225	.07797	402.97	490
000...	410	168,100	.06134	508.12	630
0000...	460	211,600	.04904	640.73	775
Cables .	630	300,000	.03355	932	The weight of cables varies with different kinds of insulation.
" ..	727.3	400,000	.02516	1242	
" ..	814.5	500,000	.02013	1553	
" ..	891.9	600,000	.01666	1863	
" ..	963.9	700,000	.01438	2174	
" ..	1030.5	800,000	.01258	2474	
" ..	1092.6	900,000	.01118	2795	
" ..	1152	1,000,000	.01006	3106	
" ..	1208.7	1,100,000	.00915	3416	
" ..	1262.8	1,200,000	.00838	3727	
" ..	1314.5	1,300,000	.00769	4038	
" ..	1364	1,400,000	.00715	4348	
" ..	1413.5	1,500,000	.00667	4658	
" ..	1458.6	1,600,000	.00625	4968	
" ..	1503.7	1,700,000	.00588	5278	
" ..	1547.7	1,800,000	.00556	5588	
" ..	1571.9	1,900,000	.00527	5898	
" ..	1630.2	2,000,000	.00500	6208	

Properties of Metals and Alloys				
Metal	Resistance per Mil Foot	Weight per Mil Foot	Weight per Cu. Inch	Melting Point Degrees Fahrenheit
Copper	10.5	.00000303	.3195	2000
Brass	42	.00000285	.300	1700
German Silver	127	.00000290	.307	....
Aluminum	19	.00000091	.096	1200
Iron (wrought)	64	.00000264	.278	2800
Platinum	56	.00000738	.778	3227
Mercury	568	.00000465	.490	—39
Nickel	77	.00000302	.318	....
Zinc	37	.00000240	.253	750

Brass is an alloy of two parts copper and one part zinc.

German silver is composed of copper, 4 parts; nickel, 2 parts; and zinc, one part — by weight.

These proportions are varied by different manufacturers and for different purposes.

CHAPTER XXIX

PROTECTIVE DEVICES

Fuses — Circuit Breakers — Oil Switches

The tables in the foregoing chapter give values of current which should not be exceeded for perfectly safe operation. The question now arises: How shall we keep more than that amount from flowing? If more lamps are connected, more current will flow; and the only way to prevent this is to open the circuit altogether.

Also electric wires stand a great many chances of being interfered with, or in some way of coming into accidental contact with each other, or with the ground, where the wire is bare or the insulation weak. The result is a "short circuit," which causes an excessive current to flow from the generator through the wires. It would not be practicable to have a man stand at the switch-board all the time and open the switch whenever such a thing occurs, so we have to provide some automatic device to prevent these excessive rushes of current.

There are two general types of device for this purpose, one depending on the heating effect of the current, the other on its electromagnetic effect. A device of the first type is called a **fuse,** one of the second is called a **circuit breaker.** Either of these will open the circuit in case the current exceeds a certain predetermined value.

A **fuse** is a wire or strip of soft metal, usually composed of lead, with small quantities of antimony and bismuth, which is inserted in the circuit so that the whole current which flows through the wire it

is desired to protect, flows also through the fuse. Under normal loads the current flows without interruption. But if the current rises above normal, sufficient heat is developed to melt the fuse. The fuse resistance is always greater, the cross-sectional area less, and the melting temperature much lower than that of copper. Consequently long before the wire reaches a temperature at all dangerous to the insulation the fuse melts and opens the circuit.

Originally fuses were mounted in the form of a wire or strip between two copper or brass terminal blocks to which the wires were attached. The terminal blocks, together with the slate, marble or porcelain base on which they are mounted, is termed a "cut-out," and a fuse so used is called an "open

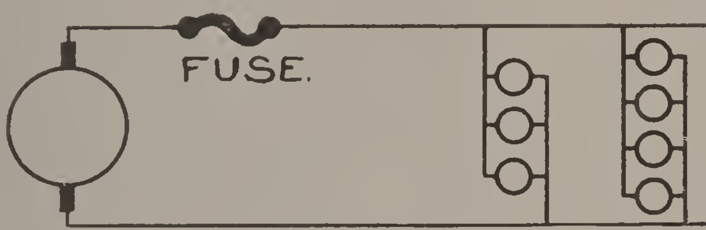


FIG. 293.

link." As a rule, fuse cut-outs are installed indoors, and on account of the fire risk from arcing and from melted metal and inflammable gases produced when a fuse "blows," they must be designed so as to prevent danger from these sources. There are on the market many kinds of cut-outs, designed to take an open-link fuse, and having a cover or other means of protection to prevent the melted metal from flying. Nearly all of these cut-outs will break and are a source of danger when the fuse blows under a very heavy overload or a short-circuit.

To eliminate the dangers incident to open link, the enclosed or cartridge fuse shown in Fig. 294 is widely used and is required by the board of fire underwriters whenever the cut-out is not mounted

in a fire-proof cabinet. In sizes up to 60 amperes, the copper ferrules shown on each end of this fuse fit into spring-contact clips. From 61 to 600 amperes, the fuses are provided with a copper blade at each end. The blades fit into clips similar to those of a knife switch. A blown fuse is thus easily with-

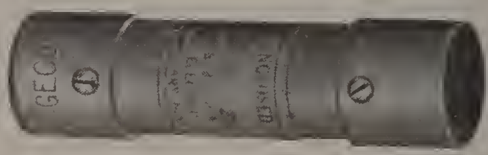


Fig. 294. — Enclosed Fuse, Ferrule Contact. General Electric Co.

drawn and a good one quickly substituted. The fuse itself is connected between the two copper blades and enclosed in the fibre tube. The space between fuse and tube is packed with a fire-proof powder, usually asbestos or silicate of magnesia. This powder must be of a character that will absorb the gases and prevent an explosion. When this fuse blows, there is no noise or arcing as in the case of the open link, which often blew with a loud re-

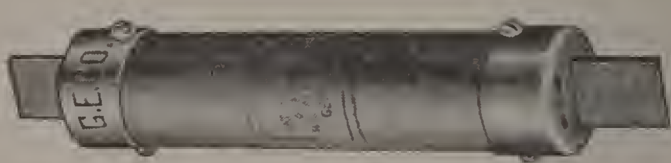


Fig. 295. — Enclosed Fuse, Knife-Blade Contact. General Electric Co.

port and with flashes which burned and blackened the switchboard on which they were mounted.

The form most commonly used in residential work is known as a fuse plug. The fuse is mounted in a brass and porcelain plug designed to screw into an ordinary Edison socket like a lamp, and is protected with a mica cover. Used as they are for

small capacities, they are not packed with silicate of magnesia. They are easily replaced, and being comparatively inexpensive, when blown the whole plug is thrown away. Plug fuses are ordinarily made in capacities ranging from 3 to 30 amperes. Cartridge fuses are made in sizes up to 600 amperes.

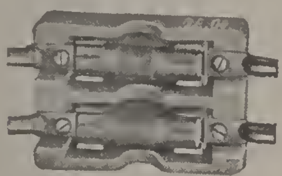


Fig. 296.

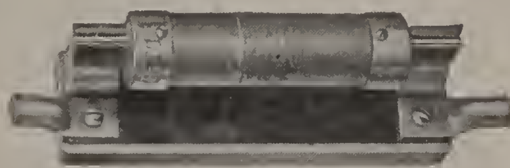


Fig. 297.

Enclosed Fuses and Cutouts.

There is a special type of fuse for use in high potential circuits. If the enclosed fuses previously described were employed on circuits of over 600 volts, there would be danger of flashing over from one copper terminal blade to the other, and maintaining the current through this arc even

Fig. 298.
Plug Fuse and Cutout.

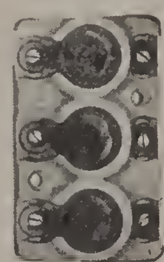


Fig. 299.

after the fuse melted. This fuse, called the expulsion type, consists of a cannon-shaped tube, open at the small end, in which is stretched the fusible wire. The surrounding space in the tube is empty, and the gases formed by the melting fuse are ignited, and the explosion blows out the arc and expels the gases in the direction in which the tube points.

Enclosed fuses are made so that they will carry indefinitely a current 10% greater than that at which they are rated when the surrounding temperature is 75° F. or less, and with 25% overload they will open the circuit. With 50% overload, starting cold, they must blow within a certain specified time, depending on the capacity — two minutes for a 100-ampere fuse. Thus a 100-ampere fuse is one which will carry 110 amperes indefinitely, will blow after carrying 125 amperes for some time, and will open the circuit within 120 seconds if 150 amperes flow through it. If 300 amperes, causing four times as much heating, should flow, the fuse would blow within 30 seconds, or one-fourth of the time.

An open link fuse is necessarily more or less variable, and its rating is less dependable. If installed in a cool place or in a draft, the heat will be dissipated more quickly, hence it will carry larger currents for a longer time than if in a warm, protected place. Fuse wire should not be clamped directly under the fuse screws, as such fuses often blow from heating due to poor contact with the clamping screw rather than from overload, also the cross-section of the wire is liable to be reduced. The fuse wire should be soldered to copper terminal clips, the clips then being clamped under the screws.

Fuses should be large enough to carry from 25% to 50% more than the maximum current when all lights are on, but in no case larger than the capacity of the wire. This gives a margin so that fuses will not blow under normal current, and still protect the system from abnormal conditions. All fuses and cut-outs should be plainly marked with the voltage and current for which they are designed.

If overloads or short-circuits are frequent, fuse renewals would become an item of considerable expense, as well as causing delay in getting current on the line again. Where this is likely to be the case, circuit-breakers are used.

A circuit-breaker is a device which uses the electro-magnetic energy of an overload rather than its heating effect to open the circuit, which it does without itself being destroyed or injured. It may best be described as a switch, the tendency of which at all times is to spring open, but is held in contact by a restraining latch. (See Fig. 300.) A coil is arranged to be energized by the line current, with a plunger which is drawn up into the coil when the current is large enough to lift it from its seat. As the plunger rises, it comes into a stronger part of the magnetic field, and by the time it strikes the latch it has acquired considerable speed — enough to trip the latch and allow breaker to open. The knurled screw is to adjust the plunger for various currents. Thus if the breaker will open on 100 amperes and we wish it to open on 85, we raise the plunger into a stronger part of the magnetic field.

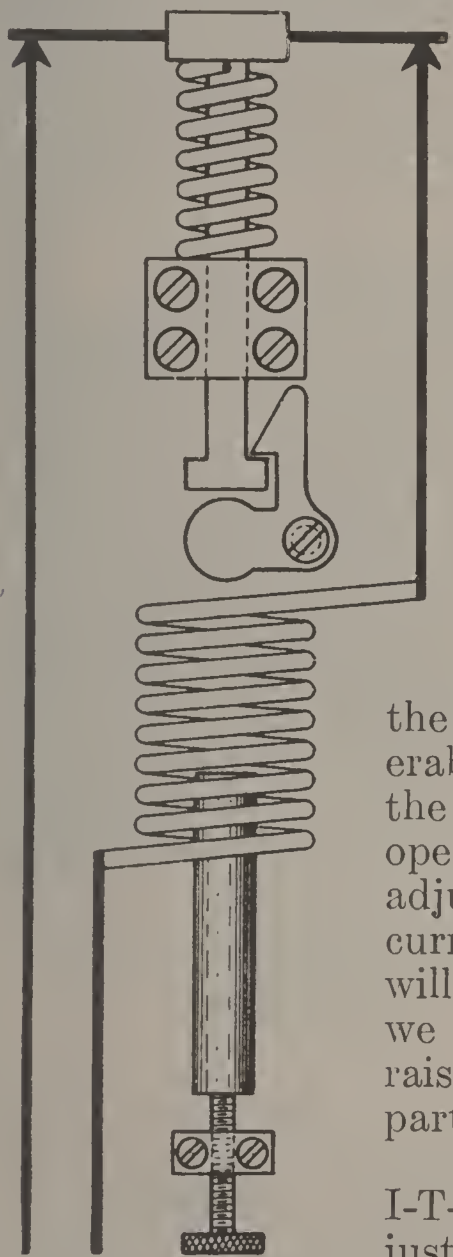


Fig. 300.

Fig. 301 shows a single pole I-T-E circuit breaker. The adjusting feature is plainly seen, also the solenoid, which consists of heavy bar copper because of the large current it must carry. The circuit is opened by the contacts at the top, which are of the knife-blade type. Carbon blocks are arranged to hold the connection until after the

copper blades have left the contacts, thus taking the arc when circuit is finally opened, and protecting the copper parts.

Figure 302 shows a circuit-breaker of the laminated type. The leaves or laminations of copper are pressed against flat copper terminal blocks as shown, the arched form of these leaves bringing the ends into contact with the blocks and keeping a tension which opens the breaker as soon as the latch is

Fig. 301. — Single-Pole, Knife-Blade Contact, I-T-E Circuit Breaker.

Fig. 302. — Single-Pole, Laminated Contact, I-T-E Circuit Breaker.

tripped. This form has an advantage over the knife-blade type in that no additional springs are required, and there is no danger of sticking.

Fig. 303 shows a General Electric circuit-breaker in which the upper contact is laminated, allowing lighter construction of the moving parts of the device. Connection with the lower contact is through a laminated spring.

Circuit breakers are used for purposes other than for protecting the circuit in case of overload.

As an instance, suppose a large motor is running and suddenly the power goes off — as when a circuit-breaker in the power house opens. The motor slows down, but does not stop before the power is on again. As long as it is running, the motor acting as a generator sends current through its own field, and this current, passing through the arm-retaining magnet on the starting box, keeps the arm from

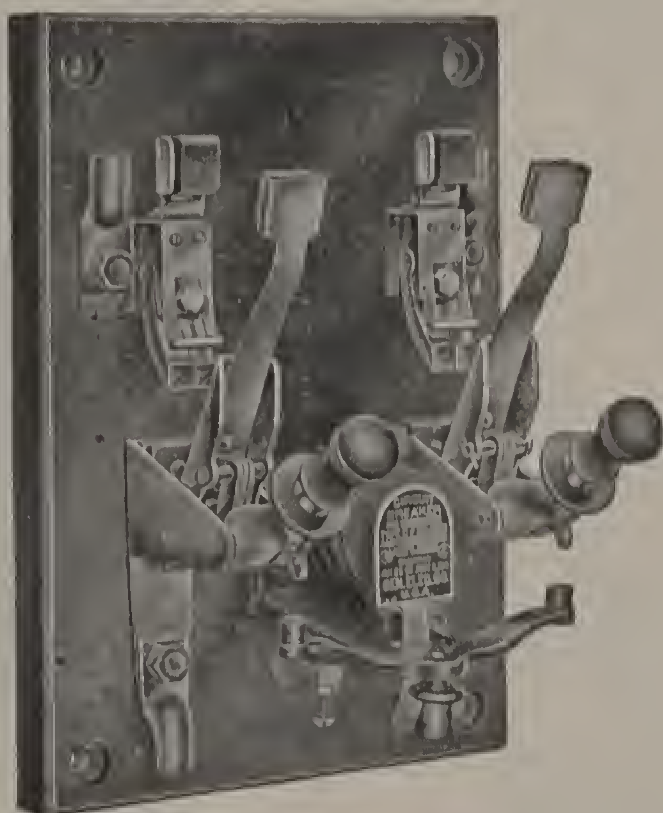


Fig. 303. — Double-Pole, Laminated Contact, General Electric Circuit Breaker.

returning to the "off" position. The power now coming on finds the motor almost stopped, but with no starting resistance in series with its armature. The result is a sudden rush of current. To obviate such a condition, motors are sometimes protected with a circuit-breaker that will respond to either an overload or the failure of line voltage. Figure 304 illustrates a breaker for this purpose. The fine wire

solenoid is connected "across the line," that is, so that it receives the full line voltage, and the latch will not stay closed unless this coil is energized.

Figure 305 shows a circuit-breaker arranged for remote control, the motor being operated from a distance by a small hand switch when it is desired to close the breaker.

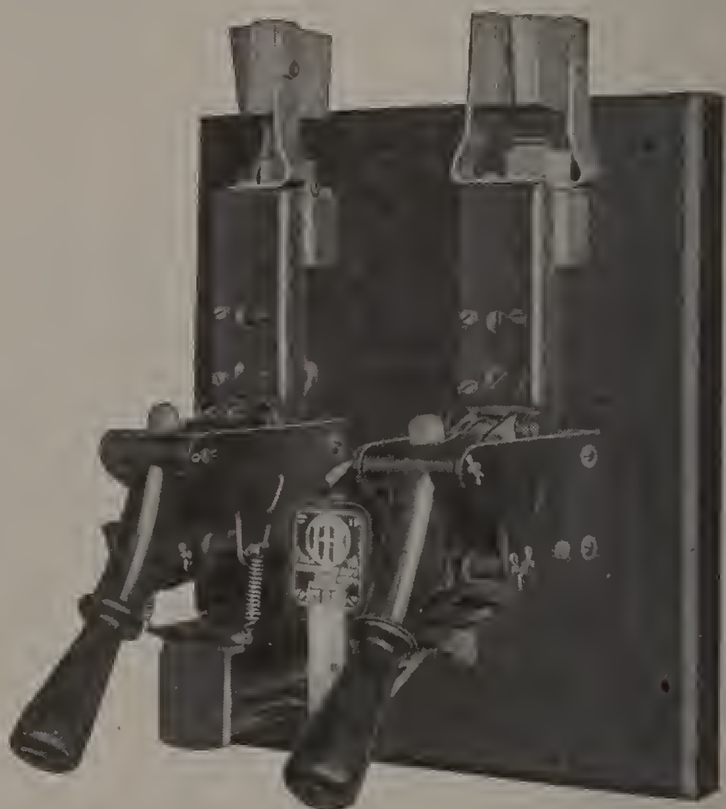


Fig. 304. — Double-Pole I-T-E Overload and No Voltage Circuit Breaker.

A circuit-breaker should have a switch in series with it, and when the breaker operates the switch should be opened before closing the breaker. Then if the short-circuit or overload that caused it to open is still in existence, the breaker is ready to respond when the switch is finally closed. The above, however, does not apply to certain types of circuit-breakers which will open even with a hand on the handle, though even then it is considered better practice to use a switch.

On circuit-breakers designed for high voltage, various means are used to interrupt the arc that forms when breaker opens. In the "Magnetic Blowout" type, the current before arcing across the opened contacts must pass through a magnet coil. This magnet produces a powerful field in the space between the opened contacts, and the reaction between this field and the arc current forces the arc to one side, and increases its length until it is finally ruptured or "blown out." The magnetic blowout is adapted to direct-current circuits up to 600 volts.

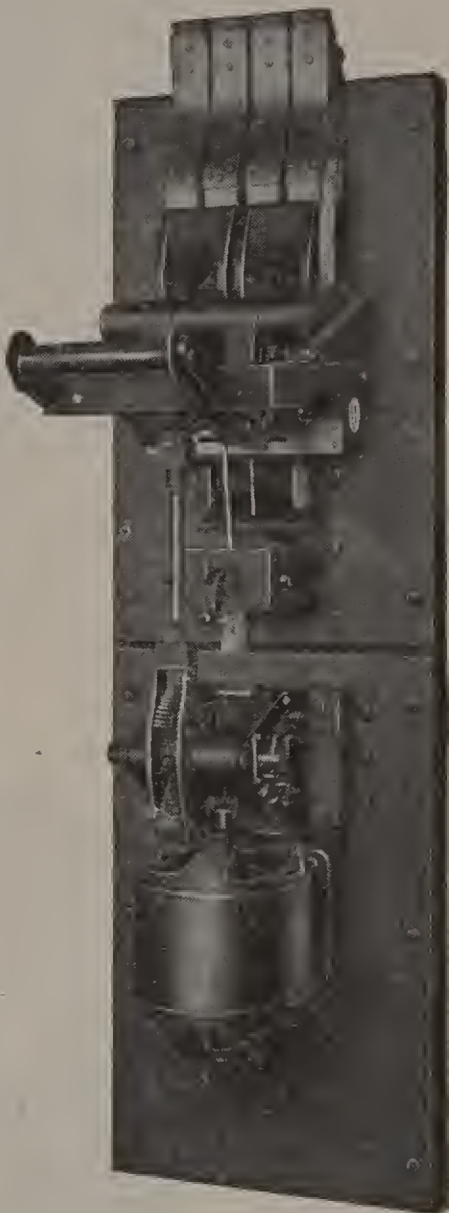


Fig. 305.— Remote Control I-T-E Circuit Breaker, Motor-Operated, 10,000 Amperes Capacity.

On higher potentials, switches are used which break the circuit under oil. A good insulating oil will interrupt an arc in a much shorter distance than air. One of these oil switches, when equipped with a tripping coil and arranged to open independently of the handle, will fill the place of both switch and circuit-breaker.

On very high-potential transmission lines the oil switches are often placed in a separate room, each pole of the switch in a fireproof vault by itself, and the switch is closed by motors operated from switchboard in the main room. The tripping coils

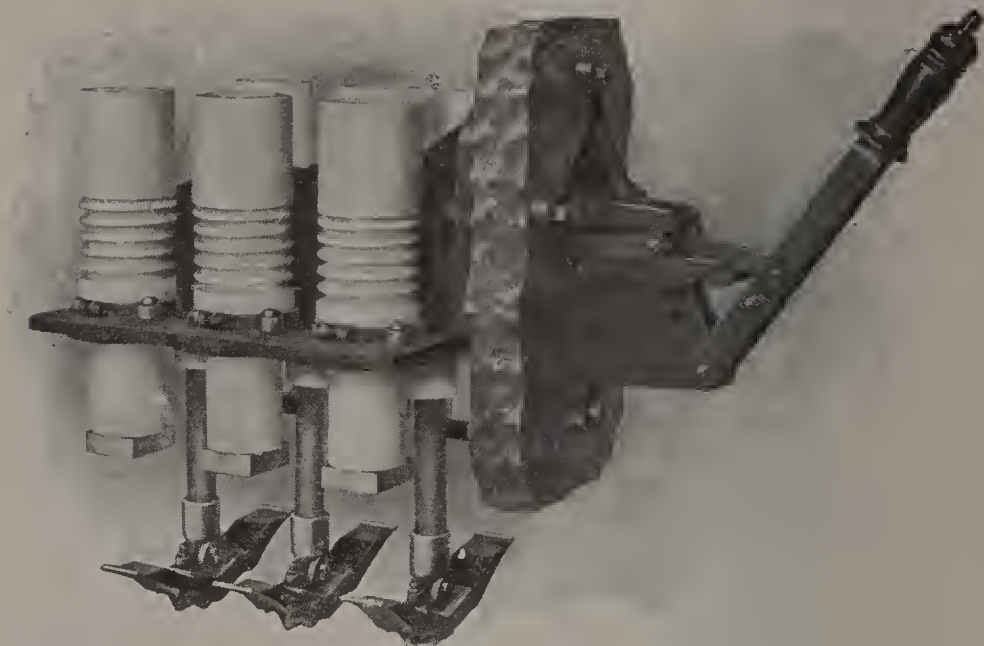


Fig. 306.—Condit Type D Oil Switch, Non-Automatic. Showing Laminated Contacts.

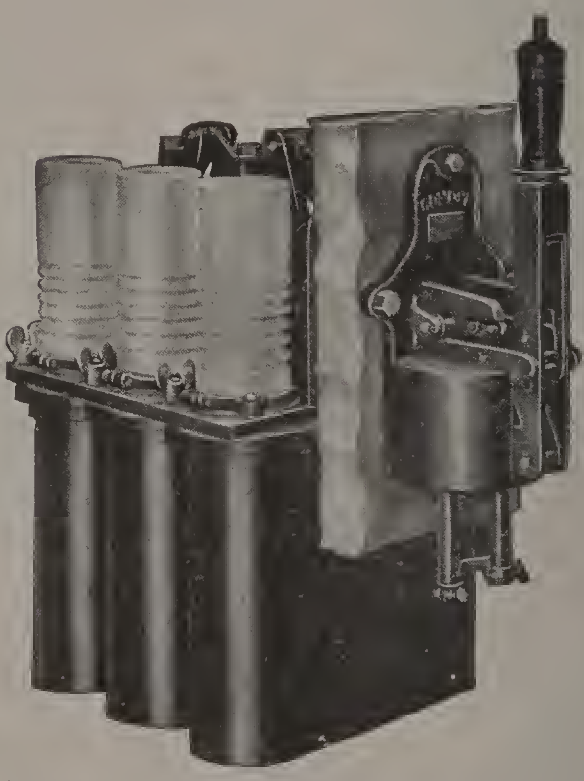


Fig. 307.—Condit Type D Automatic Oil Circuit Breaker.

Showing tripping coils, and oil tanks in which contacts are immersed.

of these switches are arranged to be operated by a hand switch, or by relays arranged to protect the circuit from various abnormal conditions, all mounted on the switchboard. Tell-tale lamps show whether the oil switch is open or closed.

Fuses and circuit-breakers serve a purpose similar to that of the safety valve on a steam boiler. If we interfere with the operation of a safety valve — weight it or tie it down — it is of no further value in preventing excessive pressure and consequent boiler explosions. Similarly if the fuses are taken out and replaced with larger ones, or with copper, they are of no further value in preventing overheating and fires.

CHAPTER XXX

INTERIOR WIRING

Underwriters' Rules — Methods — Materials

To protect life and property from danger as a result of poor workmanship, is the object of the National Board of Fire Underwriters in setting forth the rules governing electric wiring and apparatus. The principle always to be kept in mind is that wires must be put up in such a manner that they will not readily become crossed or grounded and cause short-circuits, with fires resulting from arcing or from short-circuit current heating the wires and setting fire to wood work, or any combustible material with which they may come in contact.

Some of the more important requirements of these rules are touched upon in the following pages, together with directions as to the best methods of installing wires and fittings to secure the results desired. Rubber-covered wire should be used for most interior work, though the Underwriters allow the use of slow-burning or slow-burning weatherproof wire in dry, accessible places, if properly put up on glass or porcelain insulators. Before beginning an installation, the proper sizes of wire should be determined, as illustrated in the latter part of Chapter XXXI.

Wires should not come in contact with other wires, whether bare or insulated, nor with water or gas pipes or any other conducting material near which they may pass. They should be kept from such contact by porcelain tubes or circular loom through which the wire is passed, and the tubes

securely fastened by knobs, cleats, or tape, so they will not slide away from the place they were intended to protect. An example of good overhead wiring is given in Fig. 308.

For ordinary open work, slow-burning weatherproof wire is allowable. The wires must be securely held on porcelain cleats or knobs away from each

Fig. 308. — Example of Good Overhead Wiring.

other and from the woodwork or other surface wired over, as follows:

	Distance Apart	Distance from Surface Wired Over
Less than 300 volts	$2\frac{1}{2}$ inches	$\frac{1}{2}$ inch
301 to 550 volts	4 inches	1 inch

Insulators or cleats should not be over five feet apart.

Where wires pass through floors or walls, they must be protected by a sleeve of non-absorptive and non-combustible material. Porcelain tubes or iron pipes are nearly always used, though with iron pipes the insulation of the wire must be reinforced.

In no case should wires be fastened up with wire staples, nor should they be fastened to or twisted around nails or other conducting materials.

When wires are run in unfinished lofts, in partitions, or between floors and ceilings, they must be at least one inch from any woodwork and if possible five inches or more apart. If impossible to keep

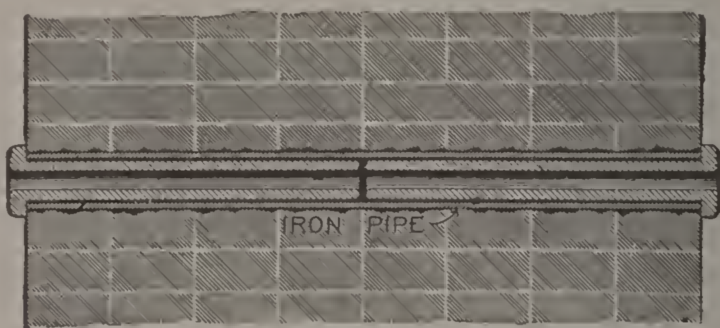


Fig. 309. — Iron Pipe Bushed with Porcelain Tubes, for Thick Walls.

them five inches apart, each wire must be encased in a continuous length of circular loom. Wires should not be fished for any great distance through inaccessible places, and even for short distances only when the inspector can easily see that the rules as to spacing, crossing pipes, etc., have been complied with. If wires must pass through inaccessible places where inspection is impossible, they must be run in metal conduit. Rubber-covered wire must be used in concealed work of this character, and, except in metal conduit, twisted or twin wires must never be used.

Whenever a joint or splice is made it should be mechanically and electrically secure before solder-

ing, then it must be soldered to prevent deterioration of the contact through corrosion, after which it must be thoroughly taped so that over the joint the insulation is as good as at any other place along the wire.

Wood Moulding is often used to conceal wiring on ceilings or walls where the appearance of wires

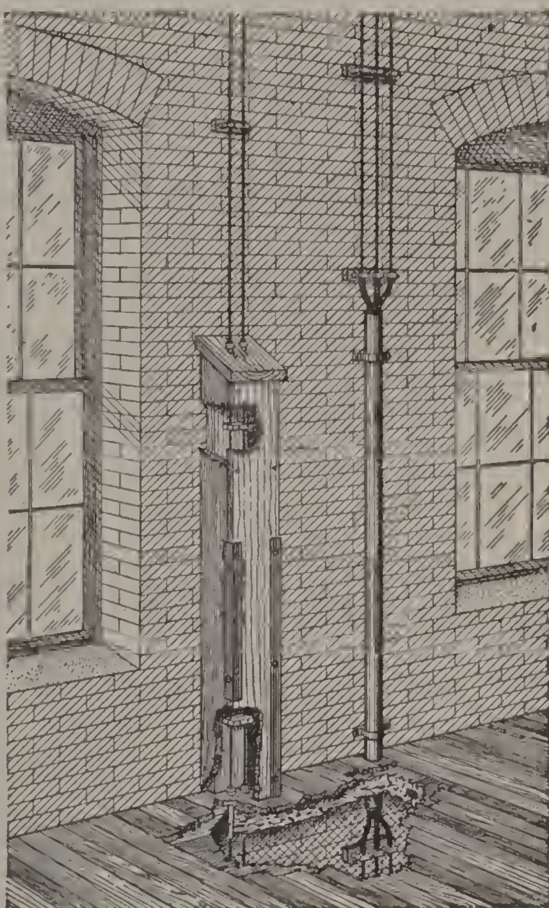


FIG. 310. — WIRES PASSING THROUGH FLOOR.
Those on left protected by porcelain tubes, those on right by iron pipe and circular loom.

is objectionable. This moulding is made to certain standard dimensions, and consists of two parts — the base, or moulding proper, with grooves for the wires, and the ornamental cap. This construction is plainly seen in Fig. 312. The base strip is first installed, then the wires are laid in the grooves and the cap secured in position with screws. Approved

rubber-covered wire must be used, and this type of work is allowed only in dry and accessible places, as leakage of current due to moisture might ignite the wood. Care must be used to see that nails or screws do not pierce the insulation.

The best method for concealed work is to run the wires in **Metal Conduit.** Standard rubber-cov-

Fig. 311. — Western Union Splice.

ered wire may be used if the interior of the conduit is lined with a smooth, hard insulating material. Uninsulated conduit or plain iron pipe may be used if the inner surface is smooth and free from burrs, and if made as strong as ordinary gas pipe, but the wire used in uninsulated conduit must be rubber-covered with an additional braid to take the abrasion

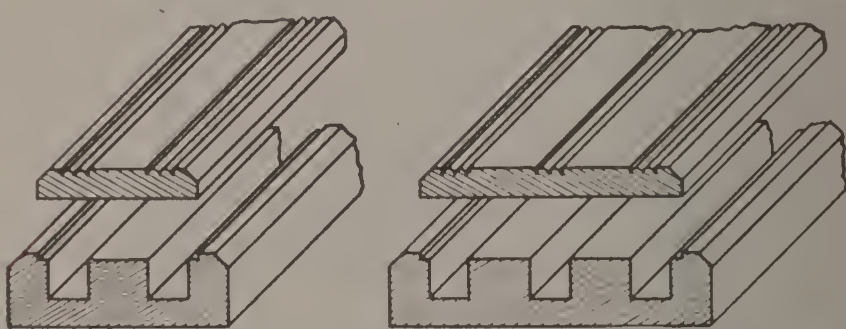


Fig. 312. — Wood Moulding, Two and Three-Wire.

incident to drawing in. The inner surface of such conduit should be coated or enameled, to prevent oxidation, with an enamel that will not be sticky and hinder pulling in the wires. The minimum permissible inside diameter of conduit is $\frac{5}{8}''$, which is approximately the inside diameter of "half-inch" gas or water pipe.

Metal conduit must be continuous between outlet and junction boxes, which must also be of metal. Where pipe enters the box, it must be securely fastened by lock nuts, and inside the box it must be fitted with an approved bushing to protect wire from abrasion on the sharp edges of pipe. Conduit systems must be completely installed before the wires are drawn in, so that subsequent work on the

FIG. 313. — GALVANIZED PIPE CONDUIT, WITH INSULATING LINING.

conduits will not injure the wires. Before current is thrown on, the conduit system must be thoroughly grounded to water pipes or to the frame of the building.

On account of the neat appearance and the protection afforded from mechanical injury, conduit systems are often used instead of open wiring. The

FIG. 314. — ENAMELED PIPE CONDUIT, WITH INSULATING LINING.

conduits are put up like steam or water pipes, and look like open plumbing. Figs. 316 to 321 show a line of outlet boxes designed for use with such a system, where neat appearance is desirable. These outlets are used like pipe fittings — T's, elbows, etc. — being made of cast iron, with hubs tapped for standard pipe threads, and arranged to protect the wires from sharp edges of the pipe. Bushings and

lock nuts are unnecessary. Fig. 321 represents one of these fittings designed for a junction box, arranged to contain a fuse cut-out and snap switches to control the branch circuits.

When **Fixtures** are supported from the gas piping, an approved insulating joint, similar to that shown in Fig. 322, must be installed as close as possible to the ceiling, and wires must be insured against possible contact with the pipes above this joint by porcelain tubes or circular loom.

In combination gas and electric fixtures, sufficient space must be allowed between gas pipe and

Fig. 315. — Conduit Outlet Box, with Crouse-Hinds Fixture Rosette.

Showing conduit with bushing inside and lock-nut outside of box.

outside casing to prevent jamming the wires. Before connecting to the lighting circuit, fixtures should be tested for grounds or short circuits. Number 18 B. & S. rubber-covered, or under certain conditions, slow-burning wire, is allowable in fixture work, but No. 16 is advised for mechanical reasons.

Drop lights are usually hung by flexible lamp cord from **Rosettes** mounted on the ceiling and connected to the circuit wires. Several designs are shown in the accompanying illustrations. The circuit wires on each side are attached to binding plates and screws in the base of rosette. The lamp

cord is attached to other binding screws in the cap. A knot should be tied in the cord where it passes through hole in center of rosette, so weight of lamp

FIG. 316. — CROUSE-HINDS CONDULET, TYPE A, WITH TWO-WIRE COVER.

FIG. 317. — TYPE B CONDULET, WITH THREE-WIRE COVER.

will not pull wire away from binding screws. In a fused rosette there are four brass contact punchings

FIG. 318. — TYPE C CONDULET, WITH METAL NIPPLE COVER.

FIG. 319. — TYPE U CONDULET, WITH PORCELAIN NIPPLE COVER.

in the cap, two on each side. A piece of small fuse wire is connected between the contacts on either

FIG. 320. — TYPE X CONDULET, WITH PLAIN METAL COVER. USED AS A JUNCTION BOX.

FIG. 321. — TYPE ZX CONDULET, FOR CUTOUTS AND SNAP SWITCHES ON BRANCH CIRCUITS.

side, the lamp cord being attached to one, and the other is connected by means of a screw to the binding plate in the base.

FIG. 322.
INSULATING JOINT.
HARVEY HUBBELL, INC.

Rosettes should be made of non-combustible, non-absorptive insulating material, and should have a base high enough to keep the wires at least $\frac{1}{2}$ inch from the surface to which it is attached. Rosettes should be fused for 3 amperes, or if fuseless rosettes are used, not more than 660 watts (12 16-C.P. lamps) should be connected to one fused circuit, as lamp sockets and the ordinary flexible lamp cord are especially liable to short circuits. Where the insulation is cut away from the line wire to connect it to the rosette, care must be used not to cut or injure the wire so as to cause it to break.

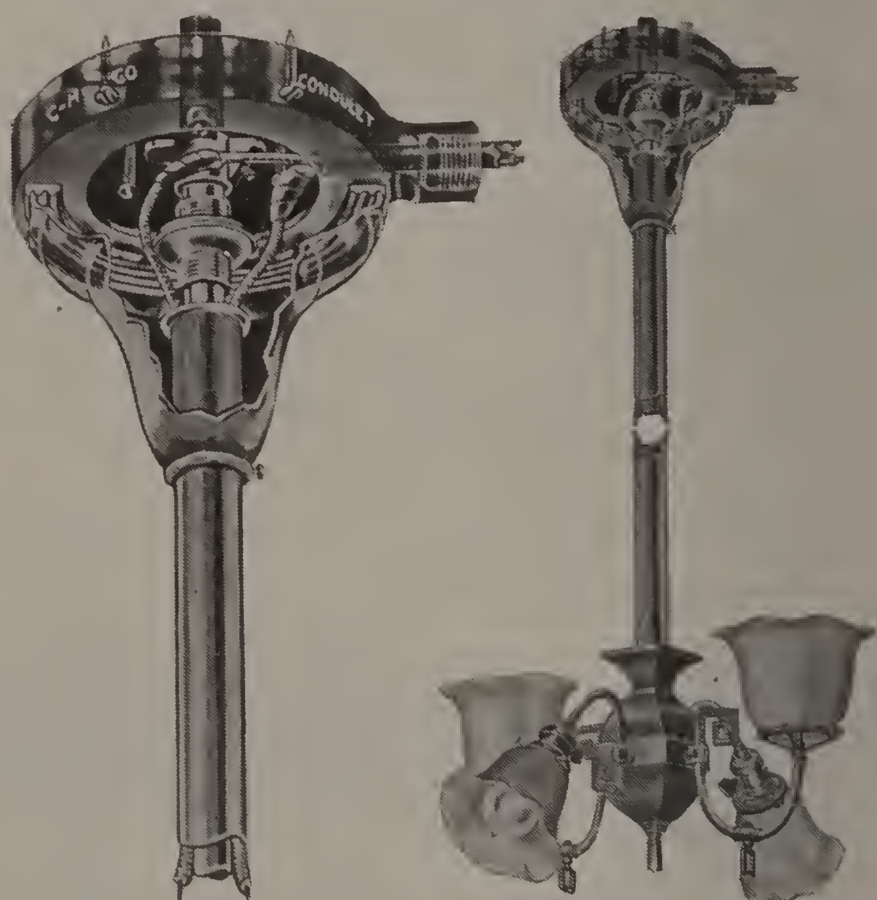


FIG. 323. — COMBINATION GAS AND ELECTRIC FIXTURE.
Note that an insulating ring is used between the condulet and canopy, as otherwise the insulating joint would be useless.

Flexible Cord is made up of several copper-wire strands, between the sizes of 26 and 30 B. & S. gauge,

FIG. 324.

FUSIBLE, FOR CLEAT WIRING.

FIG. 325.

ONE-PIECE FUSELESS.

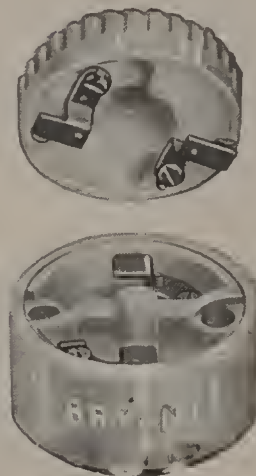


FIG. 326.

TWO-PIECE FUSELESS.

BRYANT "JUNIOR" ROSETTES.

FIG. 327. — CROUSE-HINDS CLEAT ROSETTE.

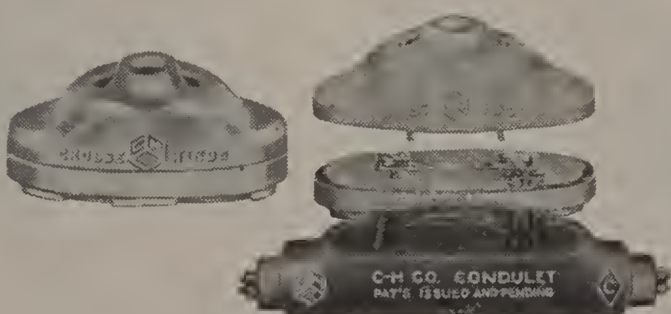


FIG. 328. — "CONDULETTO" ROSETTE. CROUSE-HINDS CO.

twisted together. The total cross-sectional area of the strands should not be less than that of a No.

18 B. & S. gauge wire. Rubber insulation is used, and instead of tinning the wires, they are held together and protected from the action of sulphur in

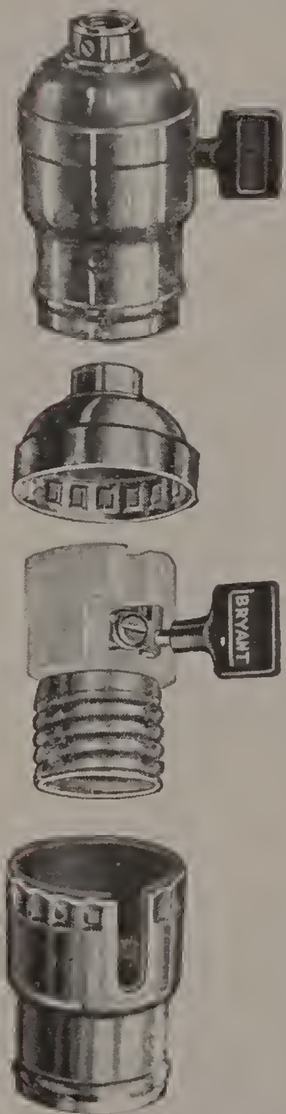


Fig. 329. — Brass Lamp Socket and Parts. Bryant Electric Co.

Fig. 330. — Weatherproof Lamp Socket. Bryant Electric Co.

Fig. 331. Hubbell Pull Socket.

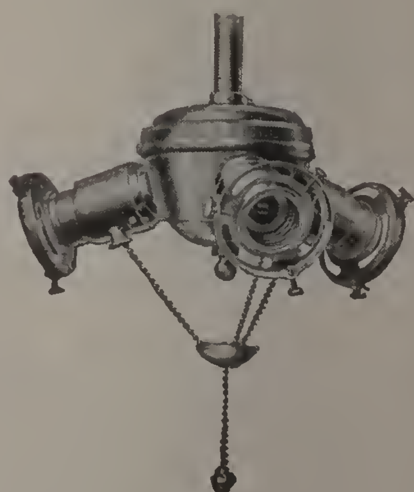


Fig. 332. — Hubbell Pull Cluster.

the rubber by a winding of cotton thread. Over the rubber insulation an ornamental braid is used, not impregnated with any weather-proofing compound. This cord is intended for supporting one or two lamps only, or for use on portable lamps, very

FIG. 333. — CROUSE-HINDS TEMPORARY SOCKET.
For temporary illuminations. Insulation need not be removed from wires, as pointed screws pierce the insulation.

small motors, or other small apparatus. It should not be used to support clusters. With metal lamp sockets, insulating bushings should be used to protect the cord where it enters the socket.

Lamp Sockets should be so constructed that the inside of the metal shell, if metal is used for the exterior, shall be thoroughly insulated from any wires attached to the inner part of the socket. Care should be taken in attaching wires to the rosette and socket to see that no ends are left to fray out and cause short circuits. All strands should be securely fastened under the screws.

FIG. 334. — CROUSE-HINDS CLEAT RECEPTACLE.

Service wires entering a building should be connected to a fuse cut-out or circuit-breaker as near as possible to the point of entrance, so as to protect

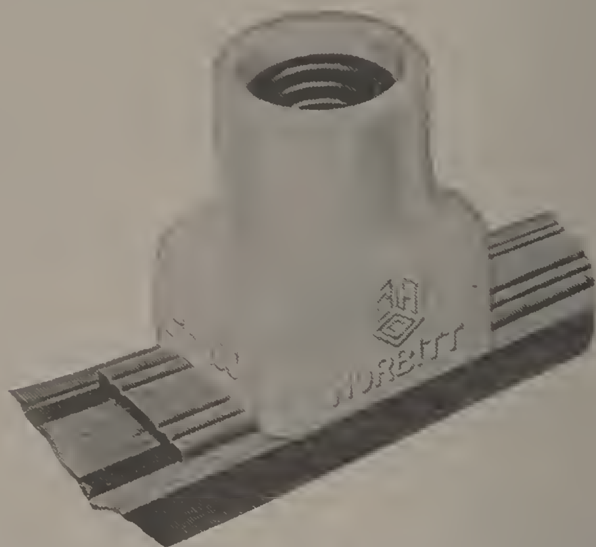


Fig. 335. — Crouse-Hinds Moulding Receptacle.

all wiring in the building. Fig. 336 illustrates a cut-out box designed to be mounted on the outside of the building or on a pole, from which the service wires are brought into the basement through conduit.

Fig. 336. — Crouse-Hinds Condulet, Type FF. Service Entrance Cutout Box.

Next after the fuses, and as near them as possible, is placed a switch, to control the entire building. Knife switches should be supported on non-

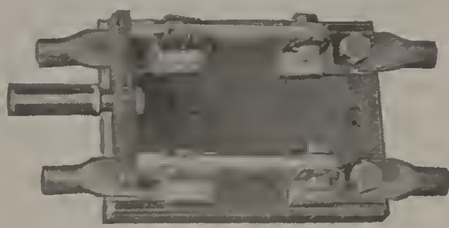


FIG. 337. — GENERAL ELECTRIC KNIFE SWITCH.

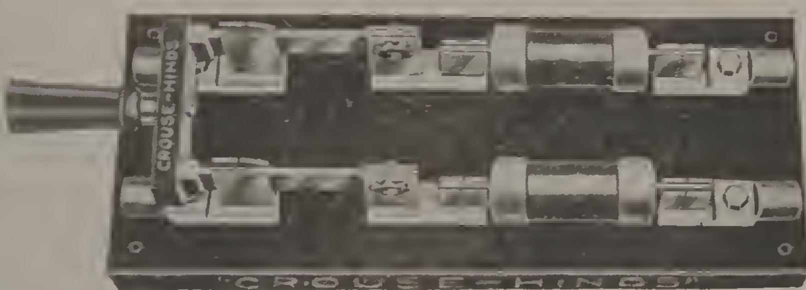


FIG. 338. — CROUSE-HINDS TYPE B, FACE CONNECTION KNIFE SWITCH, ARRANGED FOR ENCLOSED FUSES.

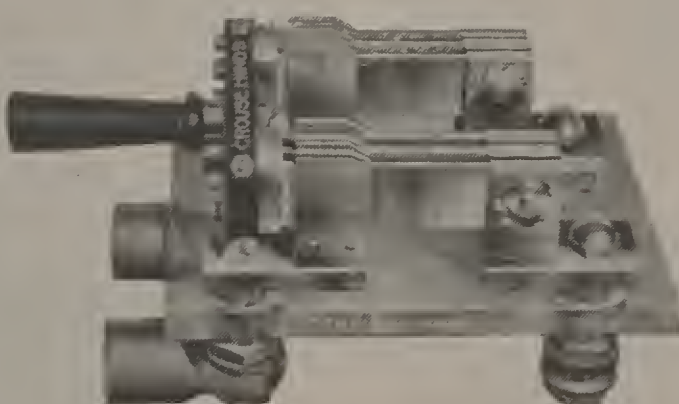


FIG. 339. — CROUSE-HINDS TYPE B, BACK-CONNECTION, HIGH-CAPACITY KNIFE SWITCH.

combustible, non-absorptive insulating material such as slate or porcelain. Hinges should be equipped with spring washers held by nuts or pins so that

Fig. 340. — Crouse-Hinds Three-Wire Service Switch, Arranged for Enclosed Fuses, in Iron Cabinet.

Fig. 341. — Perkins Snap Switch.

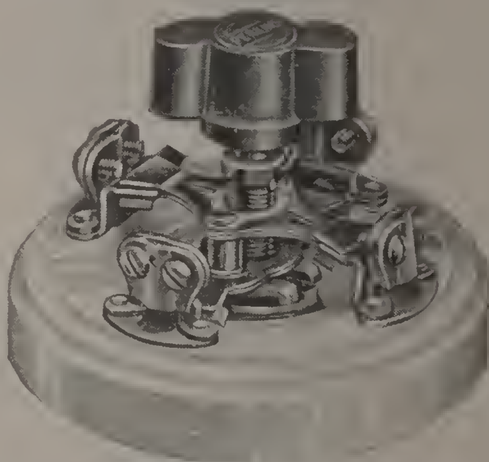


Fig. 342. — Perkins Double-Pole Snap Switch. Showing Mechanism.

Fig. 343. — Indicating Snap Switch, Mounted on Type G Condulet.

Fig. 344. — Perkins Flush Push Button Snap Switch.

a secure, firm connection is maintained. Arcing at this point would soon burn the switch so as to render it useless. Attention is called to the excellent design of spring washer on the switches in Figs. 338

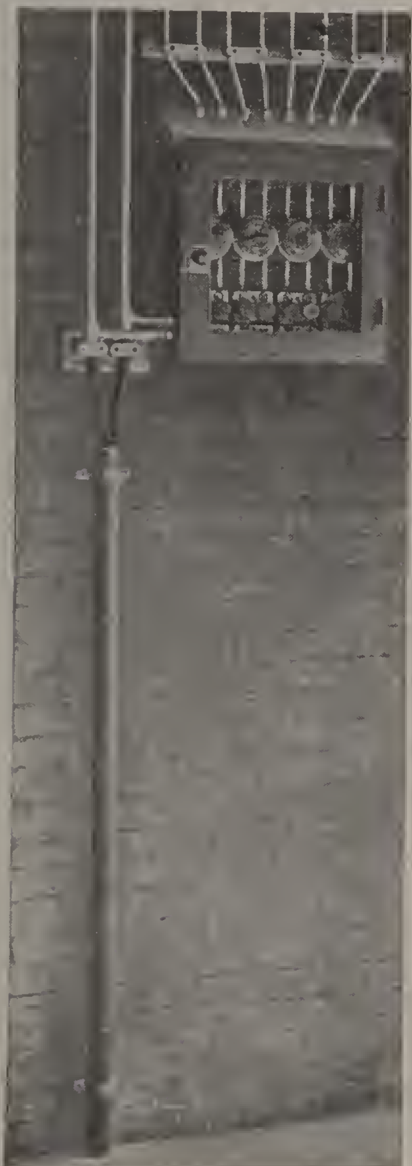


Fig. 345. — Unlined Cabinet, with Snap Switches and Plug Fuses.

Fig. 346. — Slate-Lined Cabinet, with Knife Switches and Open-Link Fuses.

and 339. They are made of spring steel, cup-shaped, tempered and copper-plated.

To work at low temperature rise, the average full-load current in a switch should not exceed 1,000

amperes per square inch of cross-section, or 50 to 75 amperes per square inch of sliding-contact area. It should be made heavy enough in any case, even for small capacities, to withstand considerable mechanical abuse. The voltage and current capacity should be plainly stamped on each switch. Knife switches should be mounted with the handle up so that they will not tend to close by gravity when open.

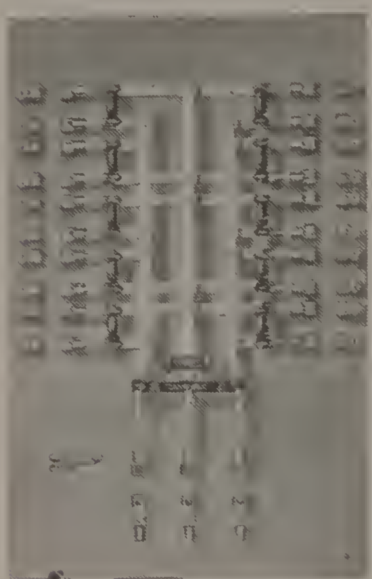


Fig. 347.

Fig. 348.

Panel Board, and Iron Cabinet with Wiring Gutter and Wood Trim. Crouse-Hinds Co.

Switches and fuses should be placed on all service wires, whether overhead or underground, and should always be accessible. Wherever in the building branches are taken off, using smaller wire than the mains, fuses must be installed of a capacity not greater than that of the smaller wire, to protect it.

Snap switches should indicate whether current is "on" or "off" to prevent mistakes or accidents. They should be marked with the voltage and current capacity, and should be large enough not to

heat excessively when carrying their rated current. Inside of metal cover should be lined with fire-proof insulation.

A very good and reliable scheme is to have all switches and fuses enclosed in an iron box, or a wood cabinet lined with iron, slate, or asbestos, or if snap switches and enclosed fuses are used, an unlined wooden cabinet is permissible. The panel board

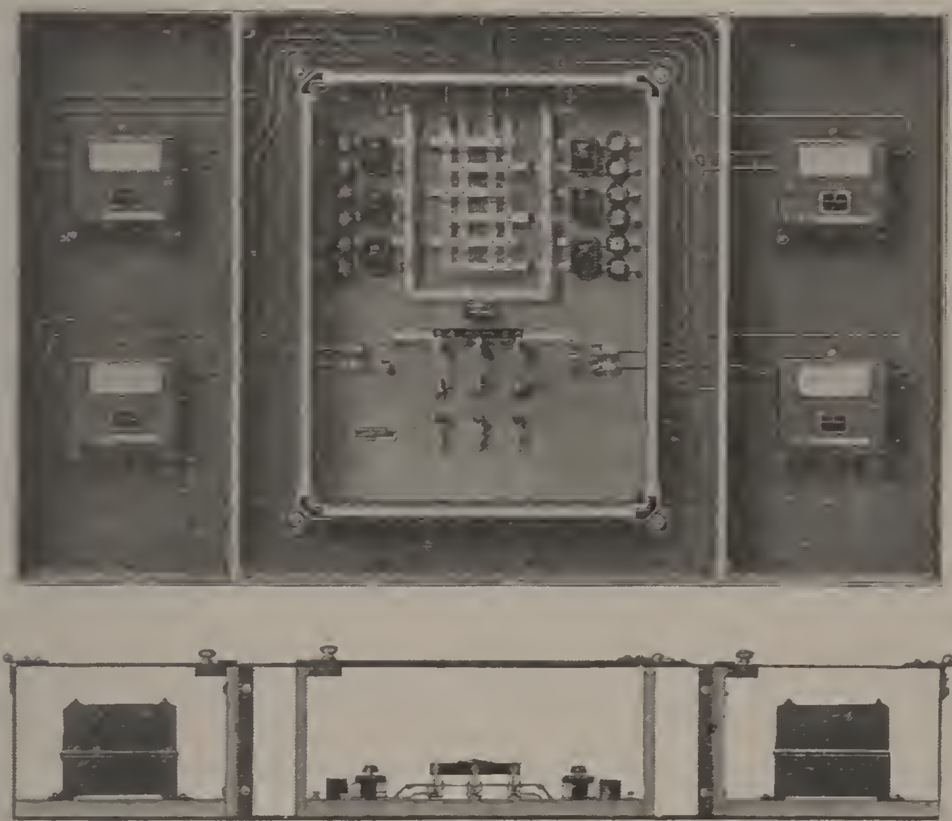


FIG. 349. — METERING PANEL AND CABINET. CROUSE-HINDS CO.

and cabinet in Figures 347 and 348 make a very neat, convenient, and attractive arrangement, especially if the door is built with a glass panel. Service is brought to the main fuses, thence to main switch, then to the bus bars, from which it is distributed to the several branch-circuit switches and fuses. With fuseless rosettes and not over 12 lights on each branch

circuit, all fuses and switches are kept in one place — an advantage readily appreciated when the lights go out.

Fig. 349 shows a meter panel and cabinet especially adapted to office buildings. When two or more rooms are rented to one tenant, the lights in all of his rooms may be connected to the same meter by changing a few screws in this panel.

CHAPTER XXXI

EXTERIOR WIRING

Underwriters' Rules — Transmission Lines

Outside wiring is fully as important as inside wiring, and in many cases more important. In the equipment of commercial power and lighting plants, it represents a large part of the investment, sometimes costing more than the complete generating station — generators, engines, boilers, building and all. Usually the voltage is much higher than is allowed for interior work, increasing the danger to life and property. There are many things to contend against from which interior wiring is largely protected.

It is important that exterior wiring be put up so it will not inflict damage on itself or other property, in case of any accident to which it is liable, and so it will not interfere with prompt action in emergencies involving danger to other property.

Near buildings, wires must be so placed as not to interfere with fighting fire, or endanger the lives of firemen, in case fire breaks out in the building. Before work is started, definite plans should be laid out. Too often this is not done, the lineman running his wires the easiest way, regardless of looks or safety.

Service wires from the line to outside of building may be of weatherproof insulation, but from there through the wall to main cut-out and service switch, it must be rubber-covered. Where wires enter the building the holes must be bushed with porcelain tubes or the equivalent, slanting upward

toward the inside so water will not follow in along the wire. Outside, the wires must be attached to insulators, and between insulator and outer end of tube each wire must have a "drip loop" as shown in Fig. 350. Rain water will thus collect and drop from the lowest point of this loop, and not tend to follow the wire into the building.

On low potential systems the wires may be brought into the building through a single iron conduit, provided that the outside end curves downward and is carefully sealed, or is equipped with an approved service head, to prevent the entrance of moisture. The outer end must be at least one foot

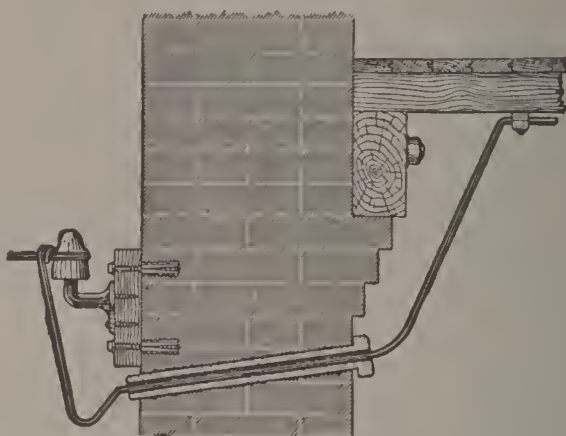


Fig. 350. — Entrance Bushing and Drip Loop.

from any woodwork and the inner end must extend to the service cut-out (Fig. 351).

Out of doors, the wires must be at least 12 inches apart, supported on petticoat insulators of very good insulating material such as glass or porcelain, and so placed that moisture cannot form a cross connection between the wires. If wooden blocks or pins are used to support the insulators, they should be given two coats of waterproof paint. Petticoat insulators (Fig. 352) are required, as in rainy weather they will nearly always have some dry surface between wire and pin to prevent leakage.

Figs. 353 and 354 show wires running over roofs. They must be at least seven feet above the highest

point of a flat roof and one foot above the ridge of a pitched roof, whether attached or not. The supporting structures should be well made, of strong material, so as not to allow wires to fall on the roof or sag so as to come in contact with persons walking on the roof.

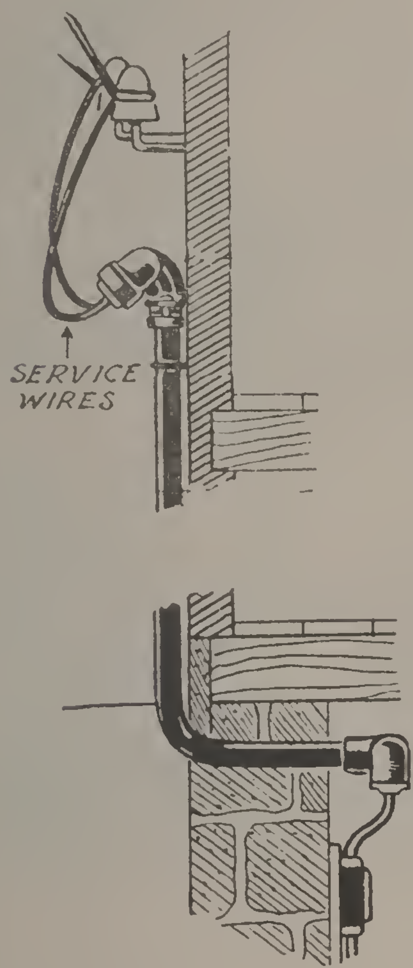


FIG. 351. — CONDUIT SERVICE ENTRANCE.

In making splices, the same rules apply as on interior wiring. The joint must be electrically and mechanically good before soldering, and after solder is applied it must be taped until the insulation is as good as elsewhere on the wire.

In tying wires to the insulators, care should be used not to put a sharp bend in the line wire, especially if it is hard-drawn copper. The simple U-shaped tie-wire plan shown in Fig. 355 is objectionable on this account. A tie made like Fig. 356 will, if properly made. hold the line-wire firmly to the insulator, without bending it.

For most high-tension transmission lines, porcelain insulators are made with a groove across the top for the line wire, and another groove for the tie wire just below and around the top. The tie is made as shown in Fig. 357. These porcelain insulators, when used for voltages over 20,000 or 30,000, are made in two or three parts, which are held together with a vitreous cement.

Fig. 352. Double Petticoat Glass Insulator. Pettingell-Andrews Co.

Electric light and power wires should not be placed on the same cross arm with telephone or telegraph wires, and when necessary to run them on the same poles, every precaution should be taken to avoid the possibility of the wires of one circuit coming in contact with those of the other. Such crossing of circuits would endanger lives of telephone or telegraph operators, as well as being a possible cause of fire in the buildings which such lines enter. The two inside pins on the cross arms carrying light or power wires should be at least 26 inches

Fig. 353. — Substantial Wooden Roof Structure.

apart, so a lineman may safely climb between the wires to reach the upper cross arms.

When the line is to operate at high potential, extreme precautions should be taken, on account of the danger likely to result from failure of any part of the structure. It must be erected so that no accident or conceivable combination of accidents would bring any of its wires in contact with other electric circuits.

If run near existing lines, it should not be nearer than the height of the taller pole line. This will

prevent any crossing of wires should the taller pole break near the ground and fall toward the lower line.

Where high-potential wires must unavoidably

Fig. 354. — Iron Pipe Roof Structure.

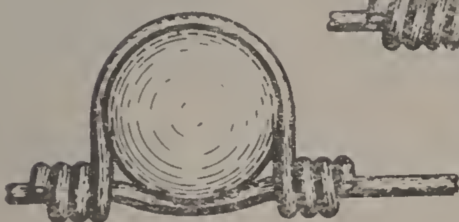


Fig. 355. Fig. 356.

Tying Wire to Insulator.

Objectionable Method. Good Method.

Fig. 357. — Method of Tying Cable to Insulator with Grooved Top.

come nearer than specified above to other circuits, or cross over them, or where they must be carried

on the same poles, extra precautions must be taken to reduce to a minimum the liability of a breakdown, and to avoid the dangerous effects of a break should

FIG. 358. — THREE PORCELAIN HIGH-TENSION INSULATORS. PETTINGELL-ANDREWS CO.

FIG. 359. — HIGH-PRESSURE LINE CROSSING OTHER LINES.

it occur. When on the same poles, the high-potential should be at least three feet, preferably five, above the low-potential wires. This lessens the

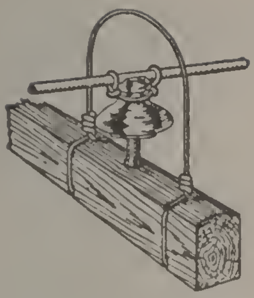


FIG. 360.
END-INSULATOR GUARD.

danger to linemen working on the low-potential circuits.

Fig. 359 shows a high-tension line crossing another line. The height and length of the cross-over span is made such that the shortest distance between the lower cross arms of the upper line and any wire of the lower line will be greater than the length of the cross-over span. With this arrangement, the wires could not touch each other, unless the tallest pole broke, even if a wire were to part at one of the

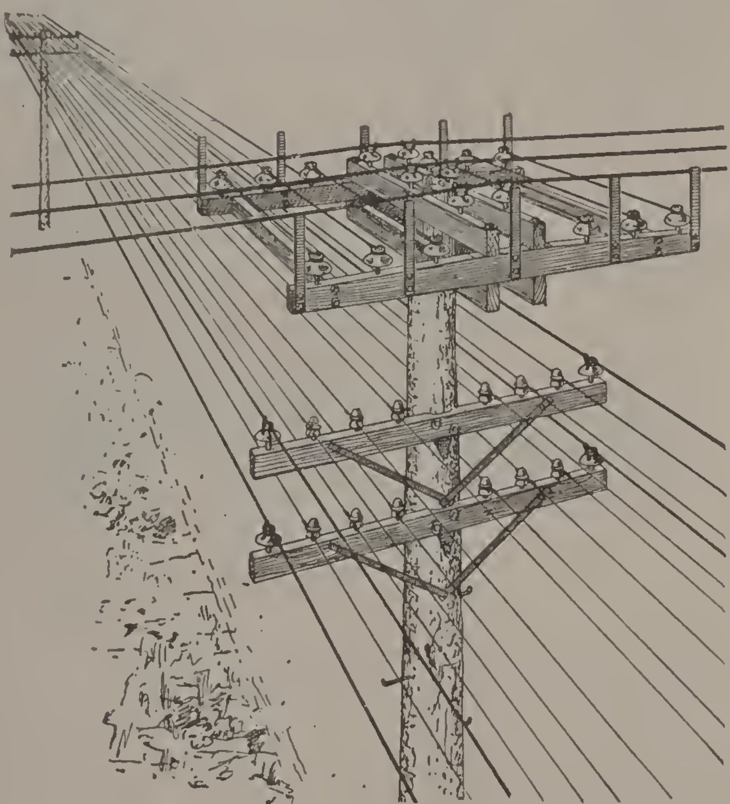


FIG. 361. — JOINT POLE CROSSING.

insulators. The outer wires of the upper line should be guarded, as shown in Fig. 360, to prevent it dropping over the end of cross arm on to the lower line in case its insulator should break or if its tie wire should become loosened.

Other methods of making crossings are illustrated in Figs. 361 and 362. The joint-pole crossing, while not as good as the first method, may be adopted if the other is impracticable. If neither method is feasible, the screen protection may be used. The screen should be supported on high tension insulators, or it should be thoroughly grounded and of such heavy construction that it will carry to ground any current a falling high-tension wire can deliver to it on short circuit.

Fig. 362.—Crossing Protected by Screen.

On the joint-pole crossing, four guard wires (shown heavier than the others) extend for one span either side of the joint pole parallel to the low-tension wires, and protect them from contact with broken wires of the upper circuit. These guard wires are on high-tension insulators. The minimum distance between high and low-tension wires should be three feet. Five is better. The end guards, to prevent wires slipping off ends of cross arms and dropping on the lower wires, should extend about six inches above the level of transmission line.

Lightning arresters must be placed on all overhead wires which connect with a station. A lightning arrester is a device which will allow a momentary excessive voltage to discharge to ground across an air gap or other barrier, but will not allow current

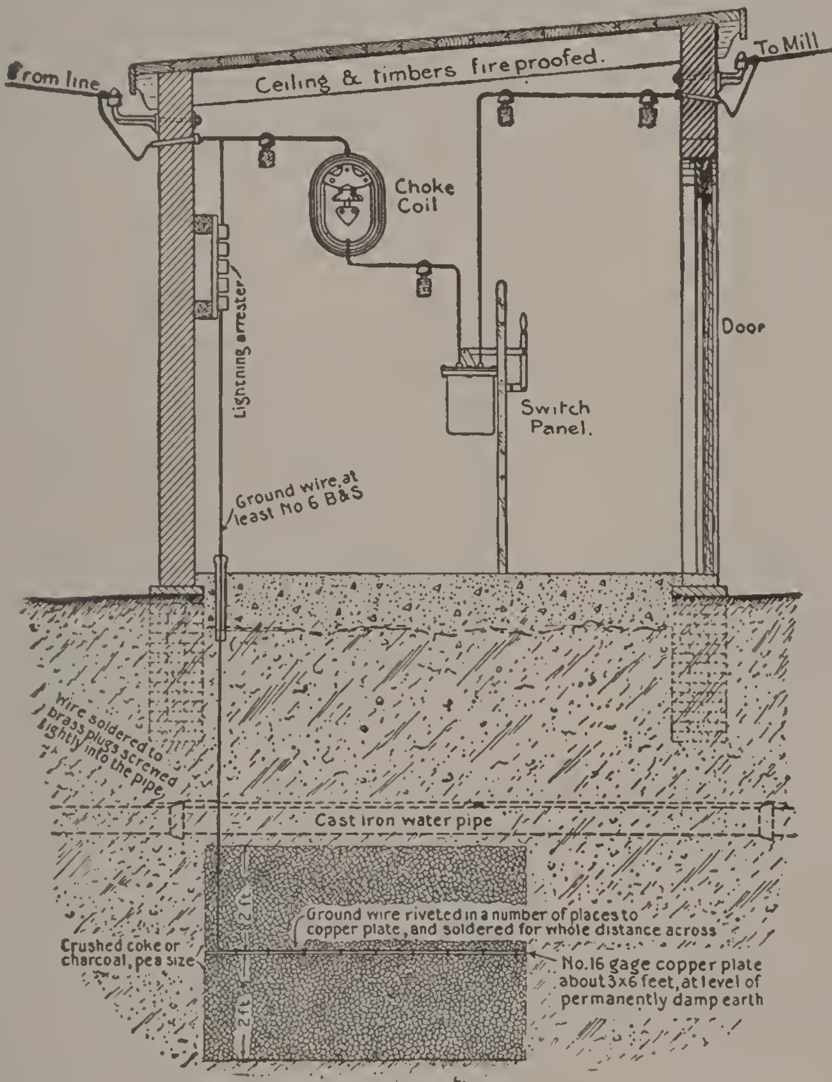


FIG. 363. — LIGHTNING ARRESTER HOUSE, WITH GROUND CONNECTION.

from the line to follow the arc so established. They should be placed as near as possible to the point where wires enter the building, and in an easily accessible place away from combustible material. Kinks and sharp bends in the wire running from the outdoor lines to the arresters and from arresters to

ground should be avoided as far as possible, as they may offer a high resistance to lightning current, which is of very high frequency, and cause it to discharge at some point where considerable damage might be done.

Lightning arresters must be connected to ground with a copper wire No. 6 B. & S. or larger. Gas pipes within a building must not be used for a ground connection. A choke coil is sometimes introduced in the circuit between arrester and generator. This acts like a dam to the lightning discharge, and the overflow is through the arrester to ground. Fig. 363 shows a very good arrangement for a power house where several arresters are to be used.

Fig. 364.
Ground Connection for Line Lightning Arrester.

It is recommended that arresters be placed at intervals along the entire system, especially if it is a long line through the country. The ground connections may be made with a one-inch galvanized iron pipe driven about 8 feet or until it reaches permanently moist earth, and extending at least 7 feet above ground. The ground wire should be securely soldered to a brass plug firmly screwed into the pipe, and both strongly stapled to the pole so there will be little danger of the connection being broken.

A good ground is very important, as the efficiency of the protection would be greatly impaired if the ground connection were poor. Wherever the earth is dry and a good ground cannot surely be obtained, an excavation 4 or 5 feet deep should be

made, and after placing the copper ground plate or iron pipe in the hole, it should be filled with crushed coke or charcoal about pea size. This improves the electrical connection between pipe or plate and earth.

When running a transmission line through the country, the poles should be as nearly as possible the same size, except where other sizes are necessary, as at points where it crosses other lines. This gives the line a neat appearance. Poles should be set in ordinary firm ground to the following minimum depths:

	Feet		Feet]
25-ft. Poles,	5	55-ft. Poles,	$7\frac{1}{2}$
30-ft. Poles,	$5\frac{1}{2}$	60-ft. Poles,	8
35-ft. Poles,	$5\frac{1}{2}$	65-ft. Poles,	$8\frac{1}{2}$
40-ft. Poles,	6	70-ft. Poles,	9
45-ft. Poles,	$6\frac{1}{2}$	75-ft. Poles,	$9\frac{1}{2}$
50-ft. Poles,	7	80-ft. Poles,	10

In solid rock they may be set two feet less, and in soft, marshy ground, or ground that is likely to become so at any time, they must be set to a greater depth, depending on conditions.

Tops of poles should be made wedge shape and painted with weatherproof paint so that they will shed rain and snow. The bottom of this wedge should be about four inches above the top of the upper gain, or place cut into the pole to receive the cross arm. The wedge should be in a line parallel with the wires.

Cedar and chestnut are used most extensively for pole timber, though juniper, pine, locust, cypress, catalpa, and oak are used to some extent, principally where it grows in abundance near the locality.

Cross arms are made from yellow pine, Oregon or Washington fir, cedar, cypress, or white pine. Wood insulator pins are nearly always made from locust. For voltages above 20,000, metal pins should

be used, as wood is liable to become carbonized from static leakage.

The life of poles ranges from 5 to 35 years, depending on

1. The kind of wood.
2. The character of the wood as regards
   - A. Heart or sap wood.
   - B. Seasoned or green.
   - C. Where grown and when cut.
3. The amount of combined air and moisture to which pole is exposed.

It appears that a combination of oxygen of the air and moisture is needed to promote growth of the destructive fungi. This is why poles invariably decay most rapidly just below the ground line.

Poles cut in winter, when the sap is down, have the longest life. The poles should be stripped of bark and seasoned under cover for several months. It has been found that green timber placed under running water for a month and then dried under cover, seasons more rapidly than if it had not been placed in water. It appears to wash out the sap and leave clear water in its place, which dries out more quickly.

Many processes have been patented for treating timbers to prevent or retard decay. The most important of these processes is that of impregnating with creosote oil. The green pole is placed in a cylinder and baked in live steam, then subjected to a vacuum for four to eight hours, or until no moisture comes from the cylinder, then creosote oil is forced into the cylinder under pressure until the pole has absorbed the required amount.

Concrete poles are being used to some extent, and, especially for high-tension transmission, towers of structural steel. The cost is greater than for wood poles, but longer spans are used and so fewer towers

are needed. Also concrete and steel have much longer life than wood poles. They are not affected to such an extent by climatic and weather conditions, nor by insects.

Wood poles carrying wires from No. 6 to No. 1 should be spaced about 150 feet apart, or 35 poles per mile. For heavier wires, they should be spaced closer, up to 48 per mile for 6 No. 0000 wires, and 66 per mile for 6 250,000 C.M. cables. Steel towers are usually spaced from 300 to 500 feet apart, or 18 to 10 per mile.

Poles should be numbered consecutively from a certain definite terminal or junction, and the number should be painted clearly upon each pole with white lead at a distance of about 6 feet above the ground. In this way a record may be kept of the life of every pole, and the line is provided with innumerable reference points which are valuable in directing repairs, alterations, etc.

All poles on curves should be well anchored, as the tension on the line wires would tend to pull them over. The cross arms on every other pole should be placed on one side of the pole, and those on the alternate poles on the other, or in other words the cross arms on adjacent poles should face each other.

The size of wire to use for a transmission line depends on several considerations. It must be large enough to be mechanically strong. On this account no wire smaller than No. 6 B. & S. should be used on pole lines. It should be large enough to carry the current without undue heating. This is determined from the wire tables. It should be large enough so that its resistance will not waste an undue amount of energy in I^2R losses, nor cause poor regulation of voltage on account of large IR drop at full load. That we may more fully grasp the meaning of these two latter requirements, let us work out the proper size of wire to be used in the following example.

Suppose we wish to transmit current from a power plant to supply sixty 110-volt incandescent lamps in a residence a half mile distant. The current required, roughly estimated at $\frac{1}{2}$ amperes for each lamp, would be 30 amps.

From the wire tables we find that a No. 10 weatherproof wire would carry the current without undue heating, but from considerations of strength we must use No. 6. Since the current must go out over one wire and return over the other, it must flow through one mile of wire, the resistance of which will be 5.28 times that given in the tables for 1000 feet. Looking this up in the table we find the total resistance will be $5.28 \times .3953 = 2.087$ ohms.

With 30 amperes flowing the IR drop in the line would be $30 \times 2.087 = 62.61$ volts, and the I^2R loss would be $30 \times 30 \times 2.087 = 1878.3$ watts. If the lamps are burned an average of three and one-third hours a night for 300 nights in the year, or a total of 1000 hours, and power costs 10c. per KW.-hour, in a year this will waste

$$1878.3 \times \frac{1000}{1000} \times \$0.10 = \$187.83 \text{ worth of power.}$$

Suppose the interest on money invested, and the taxes and depreciation in value of the copper wire were 10% per year. At 25c. a pound, one mile of No. 6 wire costs $5.28 \times 112 \times \$0.25 = \$147.84$. Its cost for one year is 10% of \$147.84 or \$14.78. We see that the power wasted costs more than 12 times as much as the expenses on the wire.

Let us try again, using larger wire, say No. 2:

$$\text{Resistance} = 5.28 \times .156 = .825 \text{ ohm}$$
$$IR = 30 \times .825 = 24.75 \text{ volts}$$
$$I^2R = 30 \times 30 \times .825 = 742.5 \text{ watts}$$

Cost of wasted power per year =

$$742.5 \times \frac{1000}{1000} \times \$0.10 = \$74.25$$

Cost of wire per year =

$$5.28 \times 268 \times \$0.25 \times .10 = \$35.40$$

Or with No. 1 wire,

$$\text{Resistance} = 5.28 \times .124 = .655 \text{ ohm}$$
$$IR = 30 \times .655 = 19.6 \text{ volts}$$
$$I^2R = 30 \times 30 \times .655 = 589 \text{ watts}$$

Cost of wasted power per year =

$$589 \times \frac{1000}{1000} \times \$0.10 = \$58.90$$

Cost of wire per year =

$$5.28 \times 306 \times \$0.25 \times .10 = \$40.40$$

If we use No. 0,

$$\text{Resistance} = 5.28 \times .0983 = .519 \text{ ohm}$$
$$IR = 30 \times .519 = 15.6 \text{ volts}$$
$$I^2R = 30 \times 30 \times .519 = 468 \text{ watts}$$

Cost of power per year =

$$468 \times \frac{1000}{1000} \times \$0.10 = \$46.80$$

Cost of wire per year =

$$5.28 \times 400 \times .25 \times .10 = \$52.80$$

Size Wire	Line Drop in Volts	Voltage Drop, in Per Cent. of Generator Voltage	Cost of Wasted Power per Year	Cost of Wire per Year	Total
No. 6	62.6	36.3	$187.83	$14.78	$202.61
No. 2	24.7	18.3	74.25	35.40	109.65
No. 1	19.6	15.1	58.90	40.40	99.30
No. 0	15.6	12.4	46.80	52.80	99.60

From the above we can see that under the conditions given, it would be most economical to use the No. 1 wire, but the voltage drop, 19.6 volts,

would be excessive, as it would be nearly 18% of the voltage required at the lamps. To have fairly good regulation of voltage at the lamps, the line drop should not exceed 5%, which in this case would be 5.5 volts. To effect this, the resistance must be less than $\frac{5.5}{30}$ or .1833 ohm, or $\frac{.1833}{5.28} = .0347$ ohm per 1000 feet. Referring to the wire tables, we find that a 300,000 C.M. cable is the smallest that will fulfill this requirement.

The following will be of assistance in forming an approximate idea of the cost of a transmission line, though obviously it is impossible to produce close general figures when labor varies from $1.75 to $3.50 per day, values of material fluctuate widely, and line construction may be carried on in summer or in winter weather.

The right of way will cost from nothing to several hundred dollars per mile.

Clearing the right of way will cost from the value of the wood taken off to $75.00 per acre or more.

Holes will cost from 25c. each in sandy soil to $1.75 or more each in hard clay or frozen ground.

For a single 3-phase 6600-volt circuit, taken as an example, the cost per mile should be about as follows:

LABOR

Digging, at 50c. per hole	$ 20.00
Fitting, at 25c. per pole	10.00
Erecting, at 30c. per pole	12.00
Distributing, at 35c. per pole	14.00
Stringing 3 Conductors	30.00
	$86.00
15% contingencies	12.60
	$98.60

Materials

Poles, 35 ft. — 40 per mile	$240.00
Cross Arms	4.50
Braces	3.50
Line Hardware	17.00
Guy Wire, 1000 ft. $\frac{3}{8}''$, 7-strand	10.00
Pins	15.00
Insulators	20.40
	$310.40
5% for extras	16.00
	$326.40
Material	$326.40
Labor	98.60
Total	$425.00

To the above must be added the cost of 3 miles of wire of the size used, the cost of obtaining and clearing the right of way, and the freight on materials used.

Poles of southern cedar or juniper cost about $3.25 for 25 ft. poles, $6.00 for 35 ft., $17.50 for 50 ft., and $28.00 for 60 ft. To this must be added the freight from the shipping point near the forests where the timber grew. Chestnut poles cost less, 35 ft. poles being sold for $4.50 to $5.00 each. Standard $3\frac{1}{4}'' \times 4\frac{1}{4}''$ yellow pine cross arms cost about $3\frac{1}{2}$c. per lineal foot. Larger sizes are special and cost more, $4'' \times 6''$, for instance, costing about 8 cents per lineal foot.

Line hardware consists of such materials as bolts, lag screws, washers, guy anchors, guy clamps, eye bolts, thimbles, guard irons, cross-arm braces, etc. These should be galvanized to prevent rusting, as they are exposed to all kinds of weather.

Cross arms are placed in the gains previously cut for them and bolted to the poles with two bolts placed diagonally. Then diagonal iron braces are applied, being attached to the cross arm at one end and to the pole at the other with lag screws.

Guy wire, being usually made up of seven strands of galvanized steel wire, is difficult to tie or splice, as can be done with copper wire. The usual method of attaching is to pass the cable through an eye, or wrap it two or three times around the pole, and, bringing the end back by the side of the main guy, clamp them together with bolts and malleable castings designed for the purpose. Where the wire passes through an eye, a thimble should be used to prevent too sharp a bend in the wire.

CHAPTER XXXII.

CENTRAL STATIONS

Operation — Equipment — Switchboards — Storage Batteries — Their Uses.

The function of the central station is to supply its customers with electricity, much as the gas and water works furnish gas or water to consumers.

An electrical power plant, whether private or public, for pleasure or profit, should be prepared to furnish current whenever there is a demand. In the case of a central station, supplying hundreds or thousands of customers, with varied requirements, it is even more imperative that nothing interfere with the continuous operation of the station. Hence reliability is the foremost requirement of the apparatus comprising the equipment.

In a commercial plant it is of vital importance that the apparatus be of a type to insure economical and profitable production, enabling consumers to obtain current at rates not only reasonable, but low enough to make electric lights preferable to gas and other illuminants, and electric motors better and cheaper for power than gas or steam engines.

A power plant and its equipment must be designed and selected to suit the conditions which it must meet. The conditions vary in different localities. For a plant of any size or importance the services of a competent engineer should be secured.

In laying out a plant, provision should be made for future growth. Many plants have been designed with no regard for this, and additions are often difficult and expensive. Not only are ground space and

future building room to be considered, but likewise the type of units and the system adopted should be such that new equipment can be selected to readily harmonize with the old.

There are three general classes of power plant:

1. **Hydraulic,** in which the source of energy is a waterfall or a considerable quantity of water flowing from a higher to a lower level through water wheels or turbines.

2. **Steam,** usually generated by burning coal under boilers.

3. **Gas,** natural or artificial, the latter produced from coal in retorts or generators, or in gas producers. Many small engines use gas produced from the more volatile constituents of petroleum, as gasoline. Some large steel plant installations use the gas from the blast furnaces.

The **Location,** so far as other conditions permit, should be near the center of the load, so as to economize in the use of copper and in the amount of energy wasted in transmission. This point is often overruled by other considerations. If a hydraulic plant, the location is fixed. When the waterfall is at a considerable distance from the load center, the power is often transmitted at high tension from the power plant at the falls to a sub-station located near the load center. Here it is transformed and distributed at low voltage to the consumers.

If a steam plant, it must be located where water is obtainable in quantities and of a quality suitable for feed water for the boilers and for cooling water for the condensers. Railway or waterway facilities should be available, so that the coal or other fuel used can be delivered at the least expense.

In coal regions, the plant is sometimes located at a coal mine. In this way the expense of transportation is saved, it being less expensive up to cer-

tain distances to transmit the power as electric current over wires than as coal in cars. Also coal may be used of a quality so poor that it would not be worth the expense of transportation away from the mine.

Other points affecting the location are: relative cost of land; suitability of the land as regards foundations, etc.; proximity to churches, schools, or other places where noise or smoke are prohibitive; and liability to legal complications.

In selecting the **Equipment,** we must consider what loads the machines will probably have to

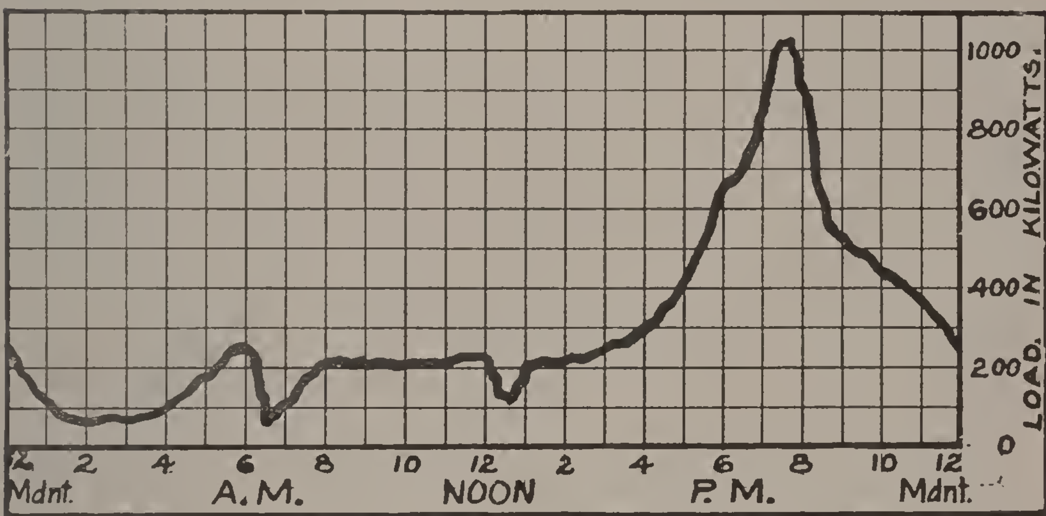


Fig. 365. — Central Station Load Curve.

carry, and for how long. Even with a large day load, of motors in factories, and special devices, such as washing machines and flat irons, in the homes, the heaviest or "peak" load comes at night, from about six, to eight or nine, in the ordinary central station.

Fig. 365 shows a typical daily **Load Curve.** To carry the peak of this load requires a maximum output of about 1000 K.W. It would be very costly to operate one set of 1000-K.W. capacity 24 hours a day for such a load curve. In a plant like this, if the equipment consisted of three 300-K.W. genera-

ting units, one set could handle the load from a little before midnight until the next afternoon, the second set being started at about 5 P.M. At 6.30 P.M., it would be necessary to throw in the third set, which could be shut down again at 8.30. At 7.30 the machines would be carrying about 12% overload. One of the three sets would not be operated very much. Thus not only are expenses reduced, but also, if one unit is temporarily disabled, the plant is not shut down. The period from midnight until 5 P.M. would suffice to make ordinary repairs, or in an emergency the two other units could handle the peak, the duration of which is about 2½ hours, on their overload capacity, if carefully watched.

In some cases an additional set is installed. This not only gives a larger factor of reliability, but also permits the overhauling of any set at any time — making it possible to keep the apparatus in the best condition. However, with the three similar units, if a spare armature, set of field coils, and minor repair parts were kept on hand, reasonable reliability would be insured, as in almost any emergency repairs could be quickly made to any machine.

Let us now take up the different types of generators, and the ways in which they are connected together when one is not enough to carry the load.

They are not often connected in series, except as boosters in railway work, or for three-wire systems or for series arc lighting or similar purposes where high voltage is desired. They are, however, frequently operated in multiple.

With two shunt machines operating in multiple (Fig. 366), suppose the voltage of machine No. 2 is slightly higher than No. 1. No. 2 would tend to force current through No. 1 and make it operate as a motor, but this increase in load on No. 2 lowers its voltage. The tendency of two shunt machines in multiple is to distribute the load evenly and operate satisfactorily.

Series-wound machines can be operated in series, but not in parallel without special equalizer connections. Referring to Fig. 367, if machine No. 1 speeds up a little or for any reason begins to gene-

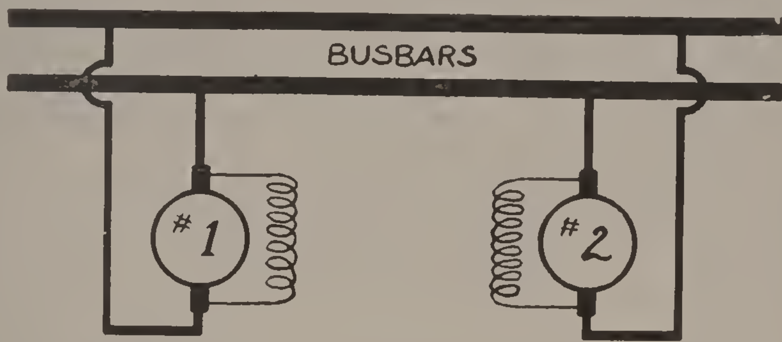


Fig. 366. — Two Shunt-Wound Generators in Multiple.

rate a little higher voltage than No. 2, it would at once commence to take more than its share of the load. With this increased current, the field would be strengthened, and cause a new increase in the

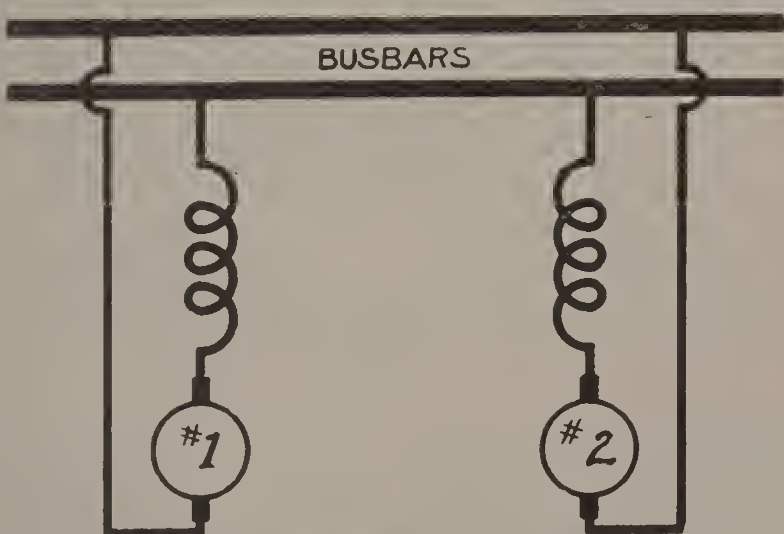


Fig. 367. — Two Series-Wound Generators in Multiple.

voltage, still further aggravating the unequal distribution of load.

To overcome this action, an equalizing connection must be made as in Fig. 368. Now if No. 1 speeds up and generates a higher voltage than No. 2, some of the current, after passing through the arma-

ture, will pass down the equalizer and through field of No. 2. In other words, the currents from both armatures, whether equal or not, will divide equally before passing through the field windings, if resistances of the latter are equal and that of the equalizer negligible.

Compound machines, combining as they do the characteristics of both shunt and series machines, can be operated in parallel if connected as shown in Fig. 369. Equalizer connections should be securely made and the equalizer itself should have as low resistance as possible.

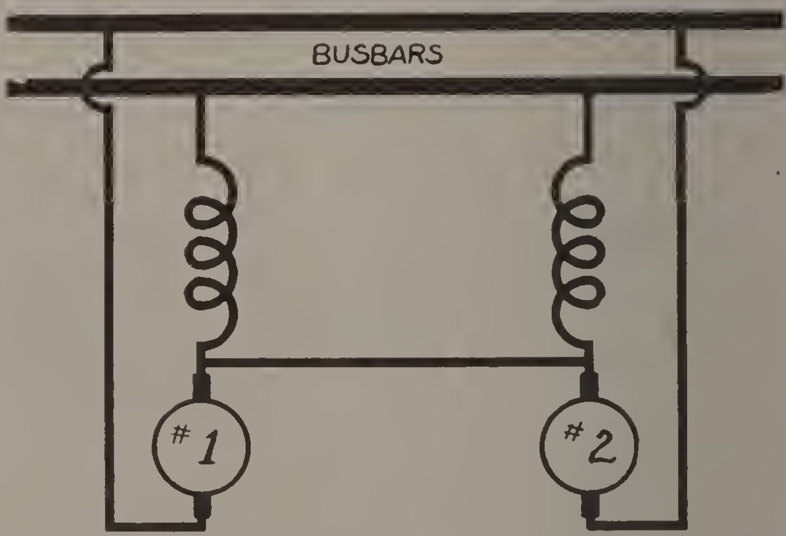


Fig. 368. — Two Series-Wound Generators in Multiple with Equalizing Connection.

If machine No. 1 is gradually becoming overloaded, we must start No. 2 and throw the two machines together. To do this, bring No. 2 up to speed and adjust its voltage until the same as No. 1, then close the equalizer switch, and finally the double pole main generator switch. Then adjust the voltage by means of the shunt field rheostat until the incoming machine takes its proper share of the load.

To shut down either machine, first reduce its voltage until it is carrying practically none of the load, then open first its main switch, and afterwards

the equalizer switch. Then its engine may be shut down.

Alternators cannot be easily or satisfactorily operated in series unless their shafts are rigidly connected together to insure their keeping in phase. However, there is very little, if any need for series operation of alternators, as transformers can be used to increase the potential to any desired figure.

For multiple operation, they must be synchronized before being thrown together. Lamps can be used for this purpose, as indicated in the diagram,

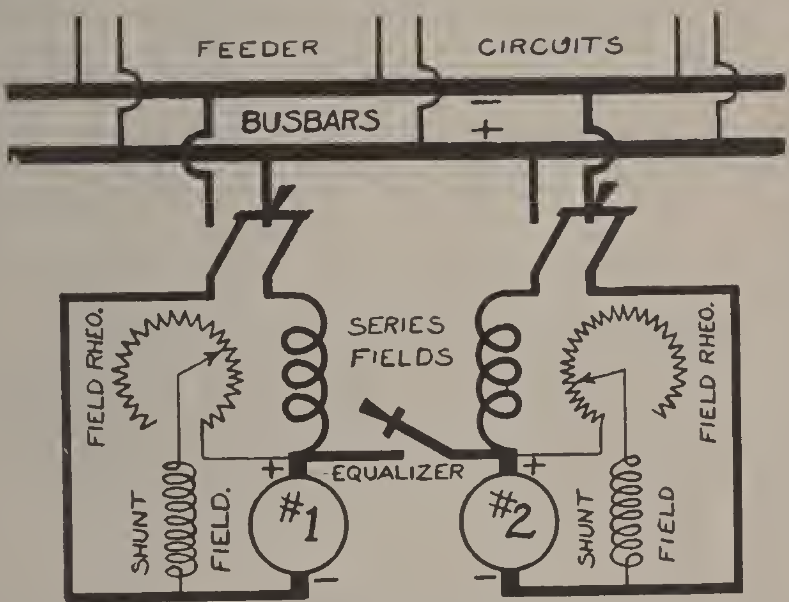


FIG. 369. — TWO COMPOUND GENERATORS IN MULTIPLE WITH EQUALIZER.

Fig. 370, though the best practice favors the use of a synchroscope or synchronism indicator, even though the cost is greater. In starting and connecting machine No. 2, it must not only be brought to exactly the same speed as that of No. 1, but into such relation that its voltage wave will be in phase with that of the first alternator. When machines are in phase there is no difference in voltage between similar points such as *A* and *C*, but full voltage between *A* and *B*. Consequently if the secondary voltage of each transformer is 110, the two lamps

will receive 220 volts and will be at full brilliancy. If the leads to *B* and *C* are interchanged, the lamps will be dark at synchronism. As 2300 is a common voltage for alternators, transformers are shown in the diagram, the lamps being connected in the secondary circuits.

As lamps do not indicate definitely the exact point of synchronism, machines might be thrown together that are slightly out of phase, causing heavy cross currents between the machines, and tripping

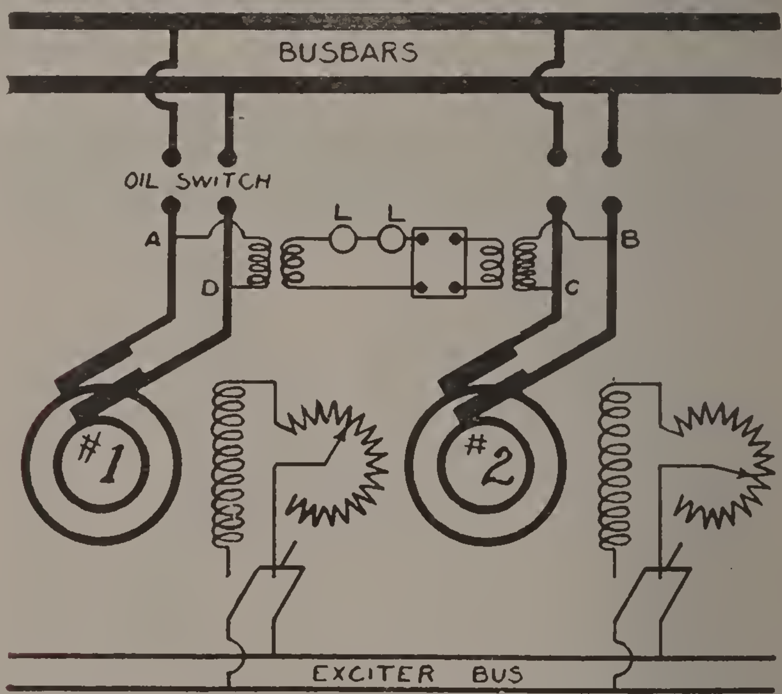


Fig. 370. — Two Alternators in Multiple.

of oil switches. To avoid this, synchronizers are used. Fig. 371 illustrates the general external appearance of a synchronism indicator made by the General Electric Company.

With reference to Fig. 372 it will be seen that this instrument is nothing more than a small delicately arranged motor. The laminated field *AA* is energized by the coils *BB* which are connected to the bus bars on the switchboard through a potential transformer. The armature winding consists of two coils *C* and *D*, connected in series with and at

right angles to each other. The outer ends of these coils are connected to collector rings 1 and 3 which are on the end of the armature shaft, while collector ring 2 is joined to the junction of the two coils at Y.

The primary of the right-hand potential transformer is connected to the machine which is to be synchronized and thrown in on the bus bars so as to operate in multiple with the machines already running. The secondary of this transformer is connected as shown to the armature and the effect

Fig. 371. — Synchronism Indicator.

of the resistance R and the reactance X is such that the current in coils C and D are practically 90° apart in phase.

The current in the coils BB and the consequent field magnetism is 270° behind the E.M.F. of the bus bars — 180° lag on account of the potential transformer and 90° lag on account of the inductance of BB. The current in D is 180° behind the E.M.F. of the incoming machine and the current in C is 270° behind the incoming machine.

If the incoming machine is in synchronism with the machines on the bus bars the voltages of the two potential transformers are in phase. The current in *C* and the field magnetism are in phase and a torque would be exerted between them so as to cause *C* to assume a vertical position. As the current in *D* and the magnetism of the field are 90° apart there is no reaction or turning effort between them. Thus at synchronism the pointer is stationary and upward.

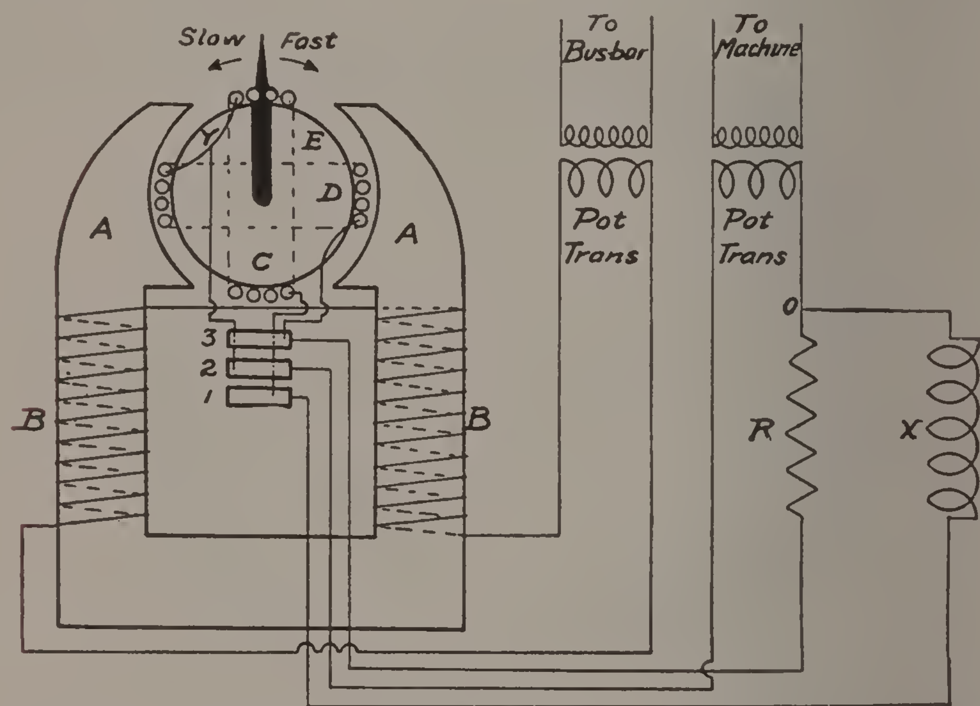


FIG. 372. — DIAGRAM OF CONNECTIONS FOR SYNCHRONISM INDICATOR.

If the incoming machine is 90° out of phase there will be no torque between coil *C* and the field, but the current in *D* will now be in phase with the field flux and the ensuing torque will cause the coil *D* to assume a vertical position. The pointer has revolved 90° either to the right or left, depending on whether the incoming machine is above or below synchronous speed. If the machines are not out of phase quite 90° the pointer assumes a position to correspond. And as the phase relation of the in-

coming machine and bus bars constantly changes, the pointer revolves. Thus by glancing at the instrument when in operation it may be ascertained whether the machine that is being synchronized is running too fast or slow, also exactly when it is in synchronism.

For convenience in operation, the controlling devices, switches, circuit breakers, instruments, field rheostats, etc., are assembled or mounted together on a switchboard of marble, slate or other insulating material.

Switchboards are often divided into sections or panels. A generator panel should have a main switch for connecting to the bus bars, a circuit breaker or fuses or both in series with the main switch to protect the machine from overloads or short circuit, a field rheostat to control the voltage, and a voltmeter and ammeter. In some cases a field switch is also mounted on the generator panel, with auxiliary contacts and resistance to take the heavy inductive discharge, so that the machine can be instantly "killed" in an emergency.

On alternating-current panels, ammeters are usually connected in each phase; thus for a three-phase machine, three ammeters should be used. On A.C. machines of over 750 volts, it is customary to connect ammeters and voltmeters in the secondary circuits of current and potential transformers. The instruments are thus insulated from the high voltage, eliminating danger to the switchboard attendants.

Feeder panels generally have a fused switch for each feeder circuit, and sometimes a circuit breaker and an ammeter.

The exciter panel in an A.C. plant is usually equipped with a main two-pole fused knife switch, a field rheostat, voltmeter and ammeter.

It is usual to mount a pilot lamp on each panel, so placed and shaded that it will illuminate without obstructing the view of the instrument scales.

Fig. 373 illustrates a small slate panel, mounted on supports of 1″ gas pipe. Mounted on a swinging bracket, the voltmeter position can be shifted, enabling it to be read from any part of the room.

Fig. 373. — Small Switchboard Panel.

Fig. 374 represents a switchboard such as would be used in the lighting plant of a large hotel, apartment house or office building. This board is designed to control one small and two large generators, and to supply forty-two feeder circuits of varying capacities. Each generator is controlled by a double-pole I-T-E circuit breaker, and three single-pole knife switches. Each is also equipped with an ammeter, a field rheostat, and a pilot lamp which burns only when the machine is running. Note that the two larger machines are idle, their

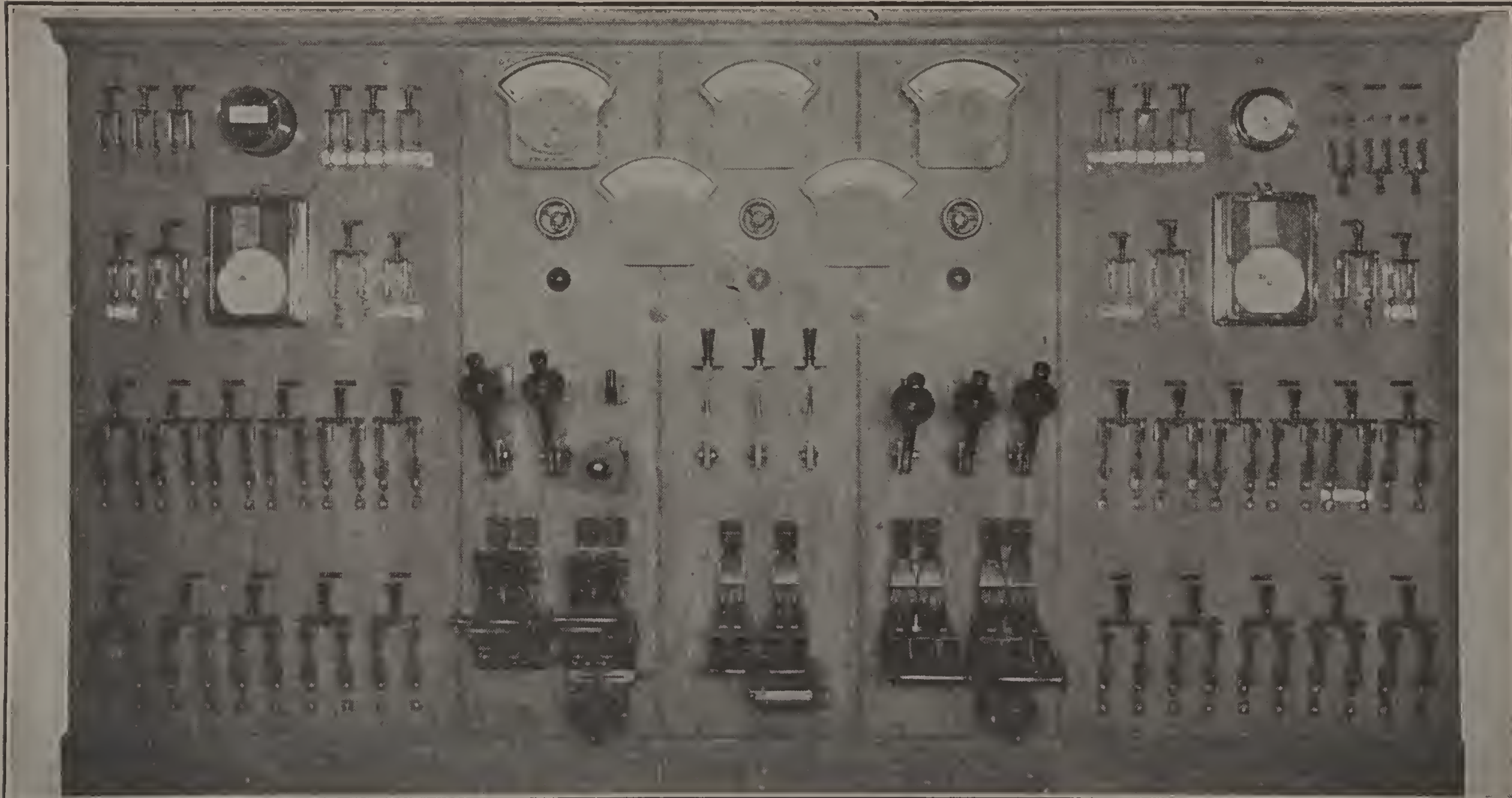


FIG. 374. — SWITCHBOARD. THREE GENERATOR PANELS. WALKER ELECTRIC CO., BUILDERS.

switches being open, the smaller machine alone showing a reading on its ammeter.

By turning back and consulting the load curve given in Figure 365, it will be readily appreciated that during the time from midnight to 3 or 4 P.M., the output of the plant is small, being about 175 kilowatts, and yet the expense for labor, etc., is practically the same for this small output as it would be for twice the amount, or 350 K.W. If the plant is offering 24-hour service, it can be readily seen why day-load motor customers are given cheaper rates. In many small lighting plants this is a perplexing

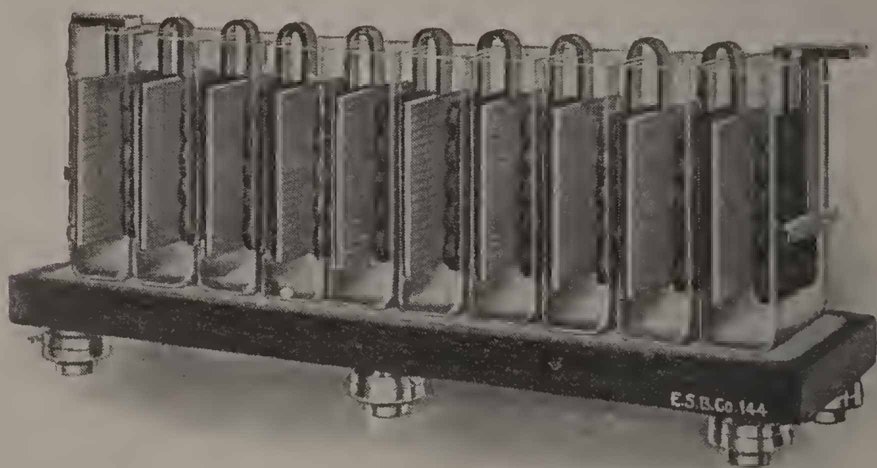


Fig. 375. — Storage Battery of Ten Cells, Electric Storage Battery Co.

question. The increase in business due to continuous operation does not seem to compensate for the increased expenses, yet if the plant is operated only from 4 or 5 P.M. to midnight, there may be a number of consumers who would become dissatisfied, to say nothing of making it very hard to get new customers. Here it is that a storage battery is oftentimes used to advantage.

As indicated by its name, a **Storage Battery** or **Accumulator** is a device in which electrical energy can be stored or accumulated (as chemical energy), and used as desired.

Essentially, in its common form, it consists of two plates, immersed in dilute sulphuric acid, contained in a jar of acid-proof insulating material, such as glass. On portable batteries where weight is objectionable, hard-rubber jars are sometimes used. In large central stations, the cells are often made of planks and lined with lead.

. The positive plates are of lead, the negative of lead sulphate. As current is forced through cell,

Fig. 376. — Large Storage Battery, in Chicago Edison Company's Plant. Manufactured by the Electric Storage Battery Co.

a counter E.M.F. is developed, similar, in a way, to the counter E.M.F. of a motor. This gradually increases, and will eventually reach approximately 2.5 volts per cell. After this point is reached, the positive plate has a dark brown appearance, due to the coating of lead peroxide. It is useless to attempt to charge the cell further.

If disconnected at this time and connected to a circuit, it will supply or give out about 80% of the

energy furnished it in charging. In other words the efficiency of a storage battery is about 80%.

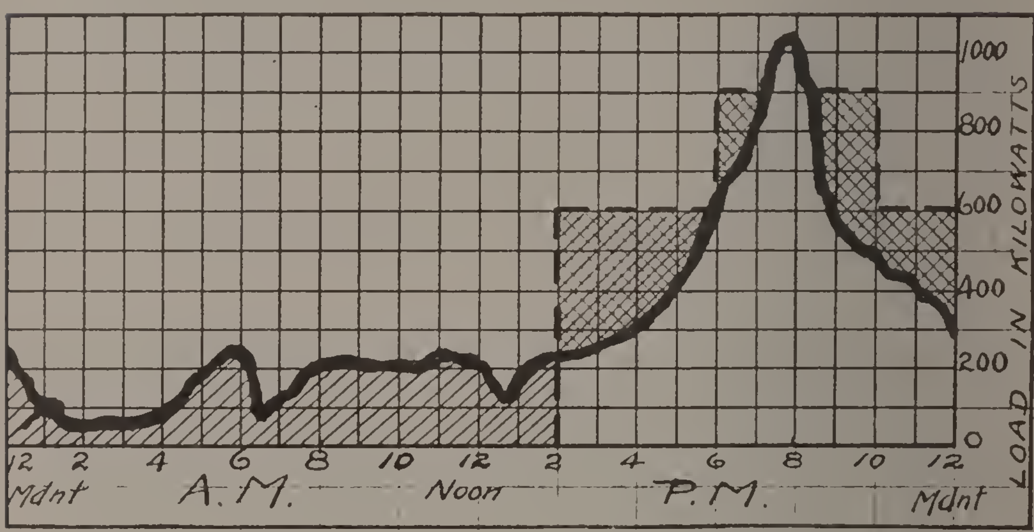


Fig. 377. — Load Curve, Storage Battery Used to Carry Day Load.

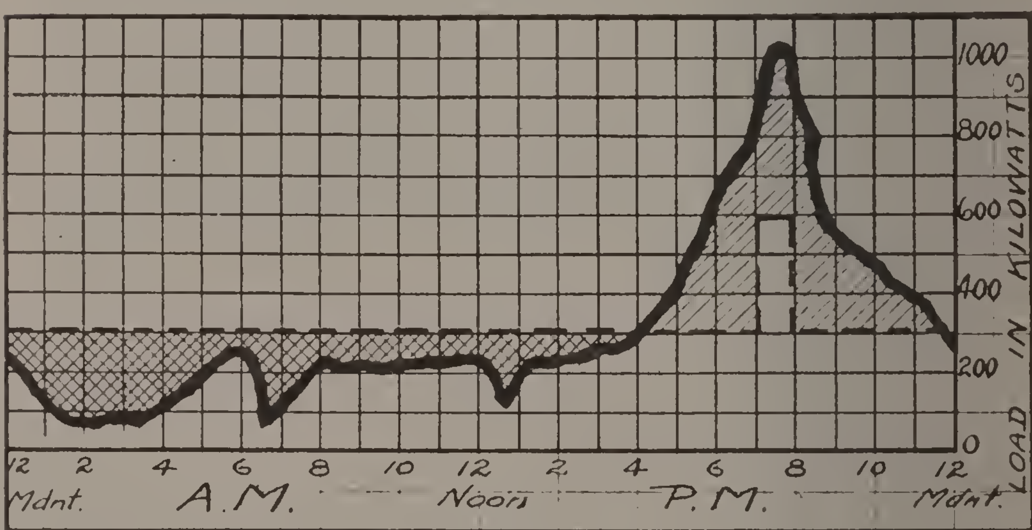


Fig. 378. — Load Curve, Storage Battery Used to Help Generators Carry Peak Load.

In preparing the dilute acid solution, or "electrolyte," acid should be poured into water, not water into the acid.

The storage battery consists of a number of cells in series — enough to give the required voltage.

As shown by the curve, Fig. 377, they can be charged in the evening, and if of the proper size, can be used to supply the demand for current from midnight to 2 P.M. while the plant is shut down.

A still more important use of storage batteries is to "float" on the line, being charged in the daytime. At peak load, in the evening, it helps out the other equipment, enabling a plant to carry a much larger peak load than otherwise possible.

Due to the large overload current capacity of storage batteries, they are a valuable asset in case of breakdown, having in some cases on record carried the entire load of the plant for a short interval while temporary repairs were being made.

Portable storage batteries are used for automobiles and similar purposes. To do away with the excessive weights of lead plates and the destructive action and objectionable fumes of sulphuric acid, Mr. Thomas A. Edison has developed a storage battery in which the electrolyte is a caustic potash solution, and the plates are of iron and nickel composition.

APPENDIX I

The following is an abstract summarizing the resolutions defining the fundamental electrical units, adopted by the International Congress of Electricians, in Chicago, 1893.

"As a unit of resistance, the **international ohm**, represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.452 grams in mass, of constant cross-sectional area, and of the length of 106.3 centimeters.

As a unit of current, the **international ampere**, represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water and in accordance with accompanying specifications,* deposits silver at the rate of 0.001118 of a gram per second.

"As a unit of electromotive-force, the **international volt**, which is the electromotive-force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the electromotive-force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C."

* In the following specification, the term silver voltameter means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment, and by noting this time, if the current has been kept constant, the current itself can be deduced.

In employing the silver voltameter to measure currents of about one ampere, the following arrangements should be adopted:

The cathode on which the silver is to be deposited should take the form of a platinum bowl, not less than 10 centimeters in diameter and from 4 to 5 centimeters in depth.

The anode should be a plate of pure silver some 30 square centimeters in area and 2 or 3 millimeters in thickness.

This is supported horizontally in the liquid near the top of the solution by a platinum wire passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling on to the cathode, the anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

APPENDIX II

English and Metric Measures.

In the English system of measurements,

1 mile = 320 rods = 1760 yards = 5280 feet = 63,360 inches.
1 rod = $5\frac{1}{2}$ yards = $16\frac{1}{2}$ feet = 198 inches.
1 yard = 3 feet = 36 inches.
1 foot = 12 inches.

In the metric system,

1 kilometer = 1,000 meters = 100,000 centimeters = 1,000,000 millimeters.
1 meter = 100 centimeters = 1,000 millimeters.
1 centimeter = 10 millimeters.

The following table, showing values of the metric in English units, will be of assistance in changing from one system to the other.

One Millimeter Equals	One Centimeter Equals	One Meter Equals	One Kilometer Equals	
.001	.01	1.	1,000	Meters
.039371	.393708	39.37079	......	Inches
.003281	.032809	3.280899	3,280.899	Feet
.001094	.010936	1.093633	1,093.633	Yards
......	......	.000621	.621382	Miles

1 inch =	2.539954	or approximately	2.54	centimeters.
1 foot =	30.47945	" "	30.48	centimeters.
1 yard =	.9143835	" "	.9144	meters.
1 rod =	5.029109	" "	5.029	meters.
1 mile =	1.6093149	" "	1.609	kilometers.

English and Metric Weights.

1 gram = the weight of one cubic centimeter of pure distilled water at its temperature of maximum density.
1 kilogram = 1,000 grams = 2.2046 pounds.